APPENDIX E

Engineering

Smith Island, Maryland Environmental Restoration Project
Feasibility Report

Appendix A
Engineering Analysis

INTRODUCTION

The following sections describe in detail the technical studies that were conducted in support of the Smith Island Environmental Restoration Feasibility Study. This work was conducted to support the plan formulation required for the study. Five distinct study areas were identified as part of the study, namely the (1) western shoreline extending from the north jetty at Swan Island to the northwest tip of Smith Island; (2) Back Cove shoreline; (3) Fog Point Cove Shoreline; (4) Terrapin Sand Cove shoreline; and (5) Sheep Pen Gut. Subsequent to study initiation, it was decided to pursue project implementation at Sheep Pen Gut under a separate study authority and was dropped from further consideration during this study process. Consequently, information contained in this appendix pertaining to proposed projects for the Sheep Pen Gut area should not be considered final.

ENGINEERING TECHNICAL APPENDIX

SMITH ISLAND ENVIRONMENTAL RESTORATION PROJECT

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SECTION 1

General

GENERAL

Smith Island is situated 12 miles west of Crisfield, Maryland and 95 miles south of Baltimore, Maryland. It is bounded to the east by Tangier Sound and to the west by Chesapeake Bay. The island is approximately 8,000 acres in area, and is 8 miles long and 4 miles wide. Smith Island can generally be described as a large marsh island with the majority of the island shoreline consisting of eroding marsh edges interlaced with many tidal creeks. The shoreline is exposed to a long open-water fetch from the west, southwest and northwest. Because of its exposed position, the entire island is subject to erosion and flooding. The island has small linear ridges running approximately North-South with upland vegetation. The largest ridges support the island's three towns, namely, Ewell, Rhodes Point and Tylerton. Small areas of these ridges reach approximately 5 feet above mean sea level, while the average elevation of the island is approximately 2 feet above mean sea level. Along the eastern and southern side of the island the shoreline consists of marsh which end abruptly at the water's edge in most places. The western side of the island contains some small sandy beaches and dunes. Several coves and formerly enclosed areas are located on the north end of the island. Historically, spits of land protected the coves providing quiescent waters in the lee of the spits. As these spits have disappeared, the marsh shorelines of the coves are more susceptible to erosion and degradation.

Smith Island has been studied several times in the past by the Corps of Engineers. The most recent study was in 1997. The "Smith Island Environmental Restoration and Protection, Maryland", Reconnaissance Report, dated May 1997 concluded that erosion is the primary threat to the island and the most pressing concern to the residents of the island. Erosion is also a threat to the environmental resources of the Smith Island complex. The report recommended the use of geotextile tubes in conjunction with stone offshore segmented breakwaters and placement of dredge material to retard the rate of erosion along the perimeter shoreline of Smith Island.

SHORELINE PROTECTION MEASURES

For the purposes of this study, four critical locations of Smith Island shoreline have been identified for remediation and various plans have been investigated. The areas considered in decreasing order of importance were (1) the western shoreline extending from the north jetty at Swan Island to the northwest tip of Smith Island; (2) Back Cove shoreline; (3) Fog Point Cove shoreline; and (4) Terrapin Sand Cove shoreline. The purpose of these plans is to reduce the rate of wetland degradation and associated impacts. Each of the plans will provide a certain level of erosion control and both positive and negative impacts to the study area environment. The following discusses the management measures that have been considered. Several of the measures were quickly eliminated based on engineering, economic or environmental considerations.

Stone Revetments

Construction of a properly designed stone revetment along an eroding shoreline will dissipate wave energy before it reaches the erodible native material of the shoreline and stabilization of the shoreline will result. In a low elevation area such as Smith Island, a sand dike would have to be constructed along the marsh edge to provide the appropriate slope for revetment construction. Due to the low elevation of the marsh, the dikes would have to be constructed significantly higher than the marsh to prevent significant overtopping of the revetment. This would in essence be similar to construction of a seawall along the perimeter of the island. The cost of such an alternative would be prohibitive and would not considered further.

Groins

Stone or timber groins constructed perpendicular to the shoreline can reduce erosion along a shoreline by trapping longshore moving littoral drift in the groin compartments. However, a system of groins does not provide any significant protection during storm events with elevated tide levels. The elevated tides allow waves to attack the shoreline directly, resulting in loss of marsh shoreline sediments in the offshore direction. Groins were not considered as a viable alternative for the study area.

Non-Traditional Bulkheads and Walls

Innovative shoreline bulkhead and walls constructed of material such as pilings, timber slats, rubber tires, jersey barriers, have been used with mixed success in the Chesapeake bay and tributaries. Typically, these structures offer only a limited amount of erosion control over a relatively short project life. Due to the extensive scope of the project area, these measures were not considered viable erosion control alternatives for the study area.

Proprietary Erosion Control Measures

Proprietary structures such as Beach Prisms, Beach Beams, Sand Grabbers, Surge Breakers, etc., have been used with limited success in the Chesapeake Bay region. Because of their limited success, and the extensive scope of the project area, they were not considered viable alternatives for the study area.

Artificial Beach Nourishment

Construction of a protective beach in several of the erosion problem areas would be an effective measure for shoreline stabilization. The gentle slope of a beach would dissipate incident wave energy and provide a buffer zone to protect shoreline areas. However, due to the wave energy along the Smith Island shoreline, this measure will only be effective when combined with stabilizing structures such as breakwaters, sills, etc. The use of artificial nourishment alone was not considered a viable alternative for the study area.

Wetland Habitat Development

Wetland habitat development, using dredged material, could reclaim some of the protective wetland that is being continually lost to erosion. Wide wetland areas would be an effective wave dissipation measure to control erosion along the remaining shoreline which offers protection to the communities of Smith Island, providing that wave energy in the area would not destroy the wetland area before it becomes fully stabilized. To insure the stabilization and protection of the wetland area, structural protection such as sills or breakwaters will be required. Therefore, wetland development without protective structures was not considered a viable alternative for the study area.

Breakwaters

The construction of a breakwater parallel to an eroding shoreline, in either an offshore or onshore location, results in a reduction of the wave energy reaching that shoreline and thus a reduction of erosive forces. In addition, the reduced wave energy zone on the leeside of an offshore breakwater usually results in a deposition of littoral drift moving along the shore in the protected area. A number of plan configurations are possible with the breakwaters. For example, a continuous length or intermittent segments of breakwater located at/or offshore of the shoreline to be protected are possible. The crest elevation can be high or low. Economics and engineering constraints as well as environmental concerns will dictate the most feasible configuration. Table 1 presents the pros and cons of the various breakwater configurations.

Dredge material may be placed in the lee of these structures to provide additional protection from overtopping waves. The areas created by placing fill shoreward of breakwaters can subsequently be planted with vegetative material to help stabilize the fill, or vegetative succession can be allowed to occur. The shoreline response resulting from the construction of breakwaters is governed by the resulting changes in the longshore sediment transport, and the onshore-offshore sediment transport in the vicinity of the breakwater. The effects on sediment transport are a function of the structure length, crest elevation, permeability, gap width, and distance from the shoreline. Generally, following breakwater construction, a new equilibrium shoreline will be established in response to the altered transport processes.

Geotextile Breakwaters

Breakwater structures in the Chesapeake Bay region are usually constructed of armor stone. However, sand-filled geotextile tubes have been used recently on the Chesapeake Bay shoreline at various locations and were considered for use in the early stages of this study. One such area where they have been used recently is located immediately west of Rhodes Point, where geotextile tubes have been placed to form a continuous breakwater. Although in general, the placement of the geotextile tubes has been beneficial in terms of retarding the shoreline erosion, the results have not been consistent. The present life expectancy of the structures based on recent experience can only be considered to be about five years. The local sponsor has voiced opposition to the use of geotextile tubes in lieu of stone breakwaters other than as a stop gap measure. In addition, experience has shown that sand is best suited to fill the geotextile tubes. Adequate amounts of sand in the dredged material used to fill the geotextile tubes is in short supply and would be better suited for use as fill material behind any protective structures. For these reasons, geotextile tubes were dropped from further consideration

TABLE 1
BREAKWATER CONFIGURATION ALTERNATIVES

DESCRIPTION	ENVIRONMENTAL	EFFECTIVENESS	COSTS 1/	CONSTRUCTABILITY
low, nearshore, continuous	protects from loss of existing wetland shoreline	allows frequent overtopping	follows alignment of shoreline, therefore high material quantities	difficult to construct due to shallow water access
low, nearshore, intermittent	loss of wetland shoreline adjacent to gaps	allows frequent overtopping; areas of unprotected shoreline	lower material quantities	difficult to construct due to shallow water access
low, offshore, continuous	mudflats in lee of structure	allows frequent overtopping	greater quantities than nearshore counterpart due to increase in water depth	allows for barge construction
low, offshore, intermittent	less potential for loss of wetland shoreline adjacent to gaps	allows frequent overtopping; areas of unprotected shoreline	greater quantities than nearshore counterpart due to increase in water depth	allows for barge construction
high, nearshore, continuous	protects from loss of existing wetland shoreline	allows less frequent overtopping	greater cost than low height counterpart	difficult to construct due to shallow water access
high, nearshore, intermittent	loss of wetland shoreline adjacent to gaps	allows less frequent overtopping	greater cost than low height counterpart	difficult to construct due to shallow water access
high, offshore, continuous	mudflats in lee of structure	allows less frequent overtopping	greater cost than low height counterpart	allows for barge construction
high, offshore, intermittent	less potential for loss of wetland shoreline adjacent to gaps	allows less frequent overtopping	greater cost than low height counterpart	allows for barge construction

Summary

For the reasons stated above, only one shore erosion control measure, namely breakwaters, was considered a viable alternative to reduce the amount of erosion currently taking place along the perimeter of Smith Island. Breakwaters can be constructed from various materials. However, due to the magnitude of the shoreline to be protected, the uncertainty associated with the performance of proprietary/unconventional structures, and local sponsor concerns, the use of stone breakwaters was considered the only viable alternative to address the erosion problems. In addition, artificial beach nourishment and wetland habitat development can be viable alternatives when used in conjunction with structures such as breakwaters and were given further consideration in this context.

As can be seen in Table 1 above, breakwaters can be configured in a number of different scenarios. Each configuration has pros and cons in relation to the environment, effectiveness, quantity of material, and ease of construction. These factors were taken into account in determining a recommended plan and are discussed further in the main report and in the following sections.

SECTION 2

Hydrology and Hydraulics
&
Coastal Processes

HYDROLOGY AND HYDRAULICS
SMITH ISLAND ENVIRONMENTAL RESTORATION PROJECT
FEASIBILITY STUDY

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PHYSICAL PROCESSES

Water Levels

Normal water level variations at Smith Island are generally dominated by astronomical tides, although wind effects can be important. Astronomical tides at Smith Island are semi-diurnal tides, with a period of approximately 12.5 hours, resulting in two high tides and two low tides each day. Tide ranges are published by the National Oceanic and Atmospheric Administration (NOAA). Tidal datum characteristics based on short-term statistics for Ewell, Smith Island reported by NOAA are presented in Table 1. Mean Lower Low Water (MLLW) will serve as the datum for this project. The Mean Tide Level (MTL) is .9 feet above MLLW with the mean tide range being 1.6 feet. Spring tides, which occur semi-monthly at or near the time of a new or full moon, result in increased tidal ranges and currents. The spring tidal range at Ewell is 1.9 feet.

TABLE 1
Astronomical Tidal Datum Characteristics at Ewell, Smith Island

Tidal Datum	Elevation in feet MLLW
MEAN HIGHER HIGH WATER (MHHW)	1.9
MEAN HIGH WATER (MHW)	1.7
MEAN SEA LEVEL (MSL)	0.9
MEAN TIDE LEVEL (MTL)	0.9
MEAN LOW WATER (MLW)	0.1
MEAN LOWER LOW WATER (MLLW)	0.0

Tide datum characteristics based on Crisfield tide statistics, are listed in Table 2. Short-term tide statistics developed by NOAA at Ewell on Smith Island (MHW of 1.7 feet, MHHW of 1.9 feet MLLW) indicate that tide ranges on Smith Island may be slightly lower than at Crisfield. However, it is not known if this is due to tidal attenuation within the island interior or if it also applies to the outer shorelines of the island. In either case, the use of the Crisfield statistics will result in slightly more conservative elevations when used for placing shore protection structure or jetty structure crest elevations.

During storm conditions, water levels are dominated by storm surge and wave setup in combination with the astronomical tide. Storm surge is a temporary rise in water level generated either by large-scale extratropical storms know as northeasters or by hurricanes. The rise in water level results from wind stresses, the low pressure of the storm disturbance and the Coriolis force. Wave setup is a term used to describe the rise in water level due to wave breaking. A comprehensive evaluation of storm-induced water levels for several Chesapeake Bay locations has been conducted by the Virginia Institute of Marine Science (1978) as part of the Federal Flood Insurance Program.

TABLE 2 Astronomical Tidal Datum Characteristics at Crisfield, MD	
DATUM	**ELEVATION (ft MLLW)**
Mean Higher High Water (MHHW)	2.2
Mean High Water (MHW)	2.0
Mean Tide Level (MTL)	1.1
Mean Low Water (MLW)	0.1
Mean Lower Low Water (MLLW)	0.0

Storm surges result in more extreme water levels, which affect flooding, overtopping of structures and maximum expected depth limited wave heights in shallow areas. The closest station location to Smith Island is Crisfield, approximately __ miles due east. The results for Crisfield are summarized in Table 3. It has been assumed that these water levels will apply to Smith Island.

TABLE 3 STORM SURGE ELEVATIONS[1]	
RETURN INTERVAL	ELEVATION (ft MLLW)
5 year	4.2
10 year	4.6
25 year	5.1
50 year	5.5
100 year	5.8

[1] Virginia Institute of Marine Science, Storm Surge Height-Frequency Analyses and Model Prediction for Chesapeake Bay, 1978.

Winds

There are no wind records available for Smith Island. Wind data for the Patuxent Naval Air Station for the period from 1945 to 1995 were obtained from the National Oceanic and Atmospheric Administration, National Climatic Data Center. Hourly one minute average wind speed and direction data were provided. The elevation of the wind instruments varied over the period of record and therefore had to be adjusted to 33 feet. A Fortran program was written which made the appropriate adjustments for elevation and extracted the highest observed wind speed for each year of record and direction from the data set. These maximum annual wind speeds are presented in Table 4.

Using these data, various return interval wind speeds for each of the principal compass directions were calculated. The approach used to estimate the return intervals was to divide the wind observations into sixteen principal compass directions, i.e. north, north northeast, northeast, etc. A Gumbel statistical distribution was fit to the maximum wind speeds for a particular direction. Using the Gumbel distribution, the return interval wind speeds were calculated for the 5-year, 10-year, 25-year, 50-year, and 100-year storm events for each of the principal sixteen directions. Table 5 shows the various return interval wind speeds by direction.

The percent frequency of occurrence for various wind speed bands for all months of the year (annual distribution) was also of interest. A Fortran program was written to extract the number of wind occurrences within specified wind speed and direction bands from the data set. The number of wind occurrences within 5 mile per hour wind speed bands for each principal compass direction is provided in Table 6. These data indicate that the winds from the WNW through the N directions (clockwise) are both more frequent and of a greater magnitude.

The percent frequency of occurrence for various wind speed bands by month was also examined. A Fortran program was written to extract the number of wind occurrences within specified wind speed bands versus each month of the year for the entire period of record. The number of wind occurrences within 5 mile per hour wind speed bands for each month is provided in Table 7. This table demonstrates that winter storms, generally known as “northeasters”, dominate storm generated coastal processes in the Chesapeake Bay region. Hurricane season typically extends from June through November, but in the local region, their greatest frequency is in the August-September time period.

Furthermore, Maryland’s seacoast is situated geographically and geologically as to escape the frequent and extreme impacts associated with the full brunt of a hurricane’s destructive path. Consequently, most tropical storms recorded in Maryland actually have been gales or fringe effects from hurricanes. Gale winds range down from 74 to 39 miles per hour. As can be seen from Table 7, there have been 58 recorded occurrences of winds greater than or equal to 40 miles per hour at the Patuxent Naval Air Station. Of those, 42 occurred between the months of December through May which is typically the time frame associated with the winter storm season, although northeaster’s have occurred as early as October (e.g. Halloween Storm of October, 1991).

Of the 18 recorded occurrences of wind speeds greater than or equal to 40 miles per hour during the hurricane months, nine appear to have been generated by tropical storms. During Hurricane Hazel (October 1954), winds in excess of 40 miles per hour were recorded for six consecutive hours with a maximum occurrence of 62 miles per hour from the southeast. Two other hurricanes, namely Connie (August, 1955) and Flossy

TABLE 4
PATUXENT NAVAL AIR STATION
ONE MINUTE AVERAGE
MAXIMUM WIND SPEED (MPH at 33 feet)
PER YEAR AND PRINICIPAL COMPASS DIRECTION

YEAR	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1945	34	27	27	39	26	29	32	28	25	26	28	31	24	43	41	33
1946	25	28	29	25	21	25	27	25	35	26	30	24	32	40	48	46
1947	30	31	24	22	23	18	23	23	22	22	25	31	30	36	40	35
1948	33	40	30	22	18	22	25	26	25	28	24	23	30	35	37	47
1949	25	30	28	20	20	29	28	24	25	25	25	24	30	38	40	35
1950	35	23	22	18	20	35	30	30	20	30	26	22	35	35	39	31
1951	40	27	25	20	28	26	30	30	28	20	25	23	24	45	33	35
1952	32	25	22	20	22	37	38	32	20	21	25	24	34	38	32	30
1953	35	30	25	18	20	18	25	26	26	22	23	30	26	30	35	35
1954	31	32	30	20	20	49	62	23	30	20	29	50	24	30	38	32
1955	30	25	30	36	30	48	34	44	24	26	29	26	28	34	35	33
1956	30	29	33	40	28	30	28	25	21	25	25	20	25	30	35	36
1957	31	23	25	23	47	29	29	29	25	25	37	22	26	36	47	31
1958	34	29	27	23	29	18	22	27	29	23	26	29	27	34	38	42
1959	25	27	25	26	19	19	25	23	26	23	25	27	27	36	38	35
1960	29	26	28	39	26	24	26	30	26	28	37	30	29	46	46	39
1961	24	24	21	36	37	34	30	30	24	22	34	34	29	37	36	36
1962	30	28	30	18	29	31	20	22	21	26	26	26	26	34	33	26
1963	24	21	20	21	16	26	24	22	24	24	25	24	29	29	31	26
1964	34	37	33	24	39	26	34	29	22	29	34	33	33	31	37	39
1965	26	29	26	21	29	31	29	24	28	31	39	29	31	42	39	34
1966	24	21	26	24	24	25	26	24	26	26	29	33	45	31	29	25
1967	25	26	22	21	18	22	24	26	26	31	26	37	29	34	39	29
1968	34	39	26	30	26	22	21	28	24	34	28	29	33	33	43	34
1969	24	24	24	21	26	21	26	29	25	26	28	24	26	34	31	26
1970	25	21	18	21	18	24	25	29	34	21	31	34	36	29	37	34
1973	31	24	26	18	21	20	22	26	24	26	29	33	30	26	26	29
1974	25	22	22	33	37	34	26	24	24	25	29	29	34	26	25	28
1975	29	18	21	18	21	29	24	25	28	30	31	30	43	42	43	39
1976	20	20	18	18	16	18	20	21	21	26	24	21	24	29	29	31
1977	22	26	18	29	35	22	22	26	24	26	26	26	29	31	34	29
1978	24	28	36	26	23	18	23	32	26	39	39	39	32	39	33	36
1979	22	19	21	26	23	26	31	28	26	28	36	28	26	31	28	36
1980	31	26	18	17	19	28	22	24	26	28	32	27	28	39	33	28
1981	26	23	19	19	21	18	24	31	28	23	23	26	72	37	28	26
1982	23	22	24	22	23	22	19	23	26	23	26	24	32	39	36	26
1983	26	26	21	22	23	22	26	28	21	22	31	26	31	36	31	36
1984	19	19	36	27	18	22	26	25	22	23	45	25	25	35	32	26
1985	21	21	17	16	45	21	28	23	23	26	26	26	28	36	35	36
1986	26	26	22	26	26	35	21	25	25	26	36	26	26	34	31	31
1987	26	28	23	23	22	23	26	22	23	26	26	34	39	34	34	34
1988	34	21	21	18	21	21	21	26	26	26	28	31	28	31	31	27
1989	23	23	23	21	26	23	21	21	26	26	30	28	36	30	31	30
1990	28	26	26	16	18	18	28	21	34	26	26	26	28	31	31	39
1991	28	31	26	18	19	17	16	34	21	28	32	26	32	28	31	34
1992	39	39	22	39	24	26	36	23	30	32	28	31	34	32	39	39
1993	33	31	21	31	28	22	22	21	31	39	24	26	23	42	31	30
1994	31	27	26	22	31	17	21	26	28	31	33	28	28	31	31	39
1995	28	19	21	19	71	23	22	37	27	23	23	26	27	24	39	33

TABLE 5
PATUXENT NAVAL AIR STATION
ONE MINUTE AVERAGE WIND SPEED (mph)
ADJUSTED to 33 Feet ELEVATION

DIRECTION	RETURN PERIODS (years)				
	5	**10**	**25**	**50**	**100**
N	30.91	34.18	38.31	41.38	44.42
NNE	29.03	32.39	36.63	39.78	42.90
NE	26.75	29.58	33.16	35.81	38.44
ENE	27.66	31.71	36.82	40.61	44.38
E	31.93	37.66	44.89	50.25	55.58
ESE	29.74	34.32	40.12	44.42	48.69
SE	30.02	34.15	39.38	43.25	47.10
SSE	28.43	31.17	34.64	37.20	39.75
S	26.68	28.89	31.68	33.76	35.81
SSW	28.28	30.93	34.27	36.76	39.22
SW	31.54	34.77	38.85	41.87	44.87
WSW	30.64	33.88	37.97	41.00	44.02
W	34.51	38.71	44.02	47.95	51.86
WNW	36.96	40.14	44.15	47.12	50.07
NW	38.18	41.59	45.90	49.10	52.27
NNW	36.02	39.40	43.66	46.83	49.97

TABLE 6
PATUXENT NAVAL AIR STATION
WIND OCCURRENCES VS. DIRECTION
NO. of OBSERVATONS 1945 to 1995

Direction/Occurrences	ONE MINUTE AVERAGE WIND SPEED (MPH at 33 feet)										
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	>45	TOTAL
N	4733	12457	7158	2788	721	156	40	6	1	0	28060
NNE	2934	10248	5518	2060	540	93	18	6	2	0	21419
NE	3184	10292	4392	1444	331	52	9	2	0	0	19706
ENE	2491	7016	2920	761	110	33	18	10	1	0	13360
E	3236	8082	2931	717	124	41	11	9	0	3	15154
ESE	2281	6729	2678	712	151	60	17	7	1	3	12639
SE	3119	11793	7144	2454	453	57	20	2	0	2	25044
SSE	3360	11329	7066	2950	455	57	10	1	1	0	25229
S	5971	15842	6847	2179	420	48	4	1	0	0	31312
SSW	3362	11405	7000	2872	453	69	10	2	0	0	25173
SW	3524	12410	8585	4282	1002	154	22	6	0	1	29986
WSW	2795	8407	5650	2550	523	117	31	4	0	1	20078
W	4674	10648	5536	2429	622	171	37	8	3	1	24129
WNW	4031	9266	5028	3590	1468	622	187	50	12	2	24256
NW	5354	12003	7972	6122	3479	1235	381	79	13	3	36641
NNW	4371	11439	7999	4821	1658	466	107	31	6	2	30900
TOTAL	59420	169366	94424	42731	12510	3431	922	224	40	18	383086

NODATA = 4682
CALM = 37387

TABLE 7
PATUXENT NAVAL AIR STATION
WIND OCCURRENCES VS. MONTH
NO. of OBSERVATIONS 1945 to 1995

Month/Occurrences	ONE MINUTE AVERAGE WIND SPEED (MPH at 33 feet)										
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	>45	TOTAL
JAN	4959	12287	7529	4433	1779	577	151	28	6	0	31749
FEB	4231	11293	7242	4211	1589	561	186	41	4	0	29358
MAR	3856	12466	8931	5339	2004	653	170	34	10	4	33467
APR	3511	12512	9117	5388	1559	365	79	35	6	2	32574
MAY	4755	14977	9129	3530	734	103	19	8	1	0	33256
JUN	5250	15550	8183	2622	417	50	11	4	0	2	32089
JUL	6159	17152	7218	1921	260	40	21	2	0	1	32774
AUG	6659	17405	6517	1623	268	56	21	2	1	1	32553
SEP	5626	15096	7290	2294	461	91	37	11	1	0	30907
OCT	4995	14690	7841	3095	725	126	32	8	3	6	31521
NOV	4452	13012	7884	3898	1265	335	80	22	1	0	30949
DEC	4967	12926	7543	4377	1449	474	115	29	7	2	31889
TOTAL	59420	169366	94424	42731	12510	3431	922	224	40	18	383086

NODATA = 4682
CALM = 37387

(September 1956) produced the three other occurrences of recorded winds between 40 and 50 miles per hour. Examination of historic records indicate an absence of tropical storm activity being associated with the remaining nine occurrences of winds greater than or equal to 40 miles per hour during the warm weather months. These recordings are believed to be associated with local weather disturbances such as thunderstorms, frontal squall lines, or extratropical storm activity.

These data bear out the fact that historically the Chesapeake Bay region is generally subjected to winds between gale and hurricane force. There was not one recorded occurrence of a wind speed greater than 74 miles per hour in the data set examined. The wind speed frequency distributions derived from these data indicate wind speeds range between 35 and 50 miles per hour for the 25 to 50 year return intervals, respectively. It was judged these conditions to be appropriate for design as waves and water levels caused by extreme wind events would result in inundation and overtopping of any protective structures and salt mash.

Offshore Waves

The numerical wave model WISWAVE set up for the Chesapeake Bay was used to convert extreme wind velocities to design deep water wave heights. The results are shown in the Table 8.

Wind data were provided by the Baltimore District in the form of a time history of speed and direction, corrected to an elevation of 10 meters, as well as a set of wind statistics where extreme values were calculated for each direction. The Patuxent Naval Air Station site is considered to be representative of the open bay area, although it is known that each site on the bay has its own local effects due to surrounding land masses and islands. However, Smith Island is a very exposed location and wind statistics should be similar to those at Patuxent.

The wind time history was used to generate a gridded hourly wind field over the Chesapeake Bay that would then drive the wave model WISWAVE. The wave model is a time-stepping directional spectral model that simulates the wave generation and transformation over open water fetches. Because of the omnidirectional nature of the wind fields, a half-plane model like STWAVE was not considered easy to implement unless many wave grids were used. The results were saved at the location of Smith Island for transformation to local areas using more appropriate techniques. The wind was assumed to be spatially uniform at each time step. The waves were simulated for the 1992-1994 time period over the region shown in Figure 1.

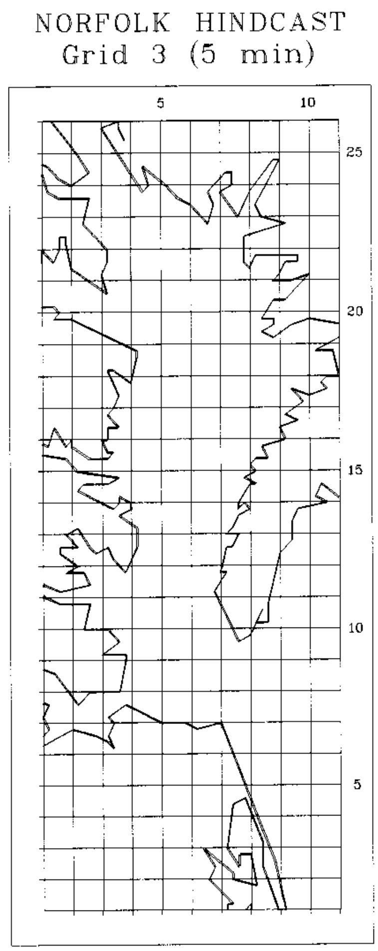


Figure 1. Chesapeake Bay Wave Model Grid Areas (Large Grid 5nmi) An Interior Grid (1nmi) was Used Locally around Smith Island

Wave model bathymetry was developed using NOAA navigation charts for offshore wave modeling. Wave transformations to local shallow water project areas were done using bathymetry developed with a combination of NOAA charts and Corps-supplied survey data. Offshore wave simulations were performed with a water level of approximately MHW, although water level position would not affect these results because wave model output was archived outside of any depth-limitation on the waves. Locations (7,19), (7,20), (8,19), and (8,20) were used as offshore wave points from which waves were transformed to the nearshore.

A lack of local wave data prevented a localized validation of the wave model; however, the model has been widely used for applications throughout the world, including the

Chesapeake Bay. The nearest validation of the model was for the Chesapeake Bay Entrance NOAA wave gauge, shown for a February 1998 storm event in Figure 2, where both ocean swell and local sea (generated in the Chesapeake Bay) are present. The processes simulated by the model are therefore assumed appropriate for application to the Smith Island site.

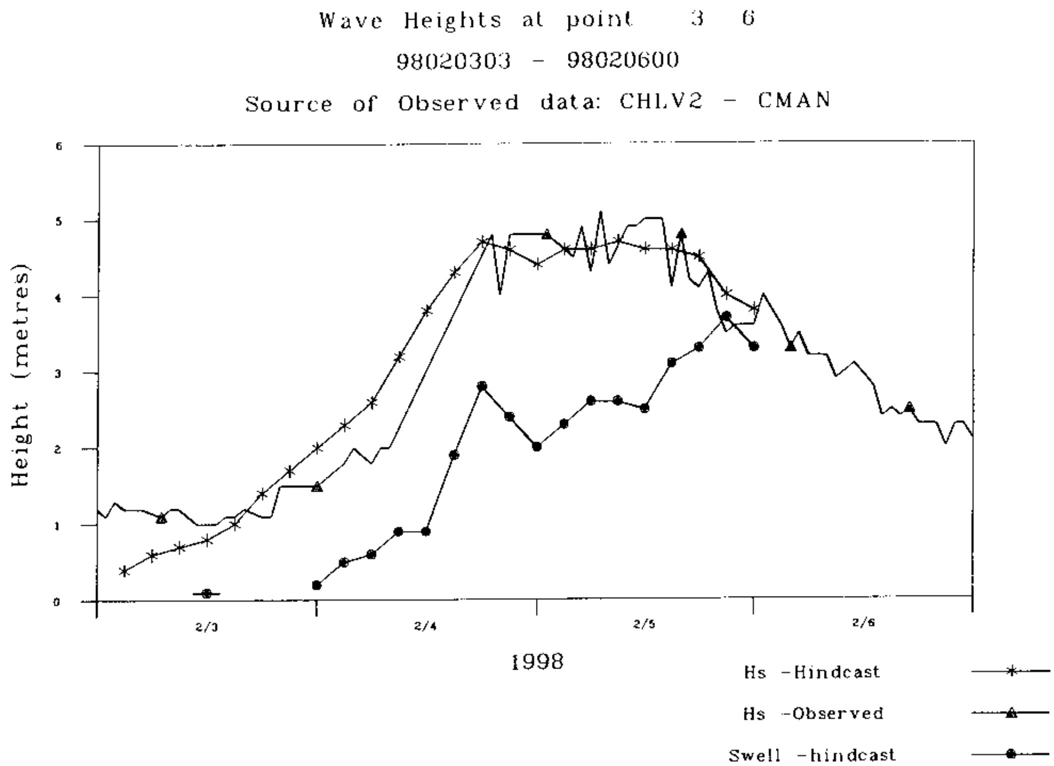


Figure 2. Wave Model Validation at Chesapeake Light for February 1998 Northeaster. Hindcasted Significant Wave Height, Hs-Hindcast, compares favorably to measurements, Hs-Observed. Swell indicates portion of wave energy entering the bay from the ocean.

The time history output from the wave model was reviewed to identify long term (near steady state) wind events that provided fully-developed sea states generated from dominant wind directions. Those conditions were tabulated for the direction ranges shown in Table 8 and extrapolated to the extreme wind speeds provided in by the Corps. Note that the extremes provided in Table 8 are zero-moment wave height, Hmo, are not maximum wave heights.

TABLE 8
OFFSHORE WAVE HEIGHTS

WIND ANGLE RANGE (FROM)	WAVE ANGLE RANGE (TO, CCW FROM EAST)		RETURN PERIOD, YEARS			
			5	**10**	**25**	**50**
315 to 15 (Northwest to North)	75 to 135	**Wind (mph)**	38	42	46	49
		Wave Ht (ft)	**6.9**	**8.2**	**8.8**	**9.2**
		Wave Pd (sec)	7.7	8.1	8.4	8.6
310 to 225 (Westerly)	140 to 225	**Wind (mph)**	33	37	41	44
		Wave Ht (ft)	**4.9**	**5.9**	**6.2**	**6.6**
		Wave Pd (sec)	5.0	5.3	5.5	5.7
220 to 170 (Southerly)	170 to 320	**Wind (mph)**	27	30	33	36
		Wave Ht (ft)	**4.6**	**4.9**	**5.2**	**5.6**
		Wave Pd (sec)	4.8	5.0	5.2	5.4
160 to 130 (Southeasterly)	290 to 320	**Wind (mph)**	29	33	37	41
		Wave Ht (ft)	**5.2**	**6.2**	**6.6**	**7.2**
		Wave Pd (sec)	5.8	6.2	6.4	6.7
120 to 23 (Easterly)	330 to 67	**Wind (mph)**	29	34	38	42
		Wave Ht (ft)	**4.9**	**5.2**	**6.2**	**7.9**
		Wave Pd (sec)	4.8	5.3	5.9	6.9

Nearshore Waves

Because of the variable bathymetry and wave breaking conditions, the waves are converted to local, nearshore wave heights using the Goda wave transformation methodology. The offshore wave grid was not used for nearshore wave transformation because the grid was not fine enough to resolve fine nearshore details and wave breaking processes in this type of environment are better resolved using programmed analytical techniques. For water depths of 10 feet or more, the ACES (Automated Coastal Engineering System, Version 1.07f), wave transformation technique was used. Because the ACES program does not support wave transformation calculations for depths less than 10 feet, the tables from the paper by Seelig and Ahrens, "Estimating Nearshore Conditions for Irregular Waves," 1980, were used for shallower depths.

Wave transformation calculations were made with waves from the north, northwest, west, southwest and south. For most of the areas under consideration, northerly winds create the most severe wave condition at the shoreline because of the greater wave fetch.

The wave transformation included the effects of wave refraction due to the angle of approach of the waves relative to the shoreline, as well as shoaling and wave breaking.

Wave heights are calculated for water depths of 6 feet, which corresponds to a bottom depth of –3 feet MLLW and a structure crest at +3 feet MLLW (nearshore breakwater), or a bottom depth of –2 feet MLLW and a structure crest at +4 feet MLLW (shallow portion of the Sheep Pen Gut jetty). These depths were chosen since a water level at the crest of a stone structure is often the most severe design condition. Table 9 shows nearshore design waves that result from transforming the northerly offshore waves. These waves are the most severe and are used for structural design.

Wave heights are also calculated along the Sheep Pen Gut jetty alignment for water depths of 8, 10 and 12 feet, corresponding to bottom depths of -4, -6, and -8 feet MLLW, with a jetty crest elevation of +4 feet MLLW. The latter condition might apply to the jetty head in –6 feet of water after future scour deepened the water seaward of the structure. Table 9 shows nearshore design waves that result from transforming the northerly offshore waves. These waves are the most severe and are used for structural design.

TABLE 9
NEARSHORE DESIGN WAVES

Water Depth (ft)	**25 Year Design Wave Condition**			**50 Year Design Wave Condition**		
	T_s (sec)	**H_s (ft)**	**H_{10} (ft)**	**T_s (sec)**	**H_s (ft)**	**H_{10} (ft)**
6	8.8	4.3	5.2	9.2	4.4	5.3
8	8.8	4.8	5.8	9.2	4.9	5.9
10	8.8	5.0	5.9	9.2	5.1	6.0
12	8.8	6.1	7.1	9.2	6.1	7.2

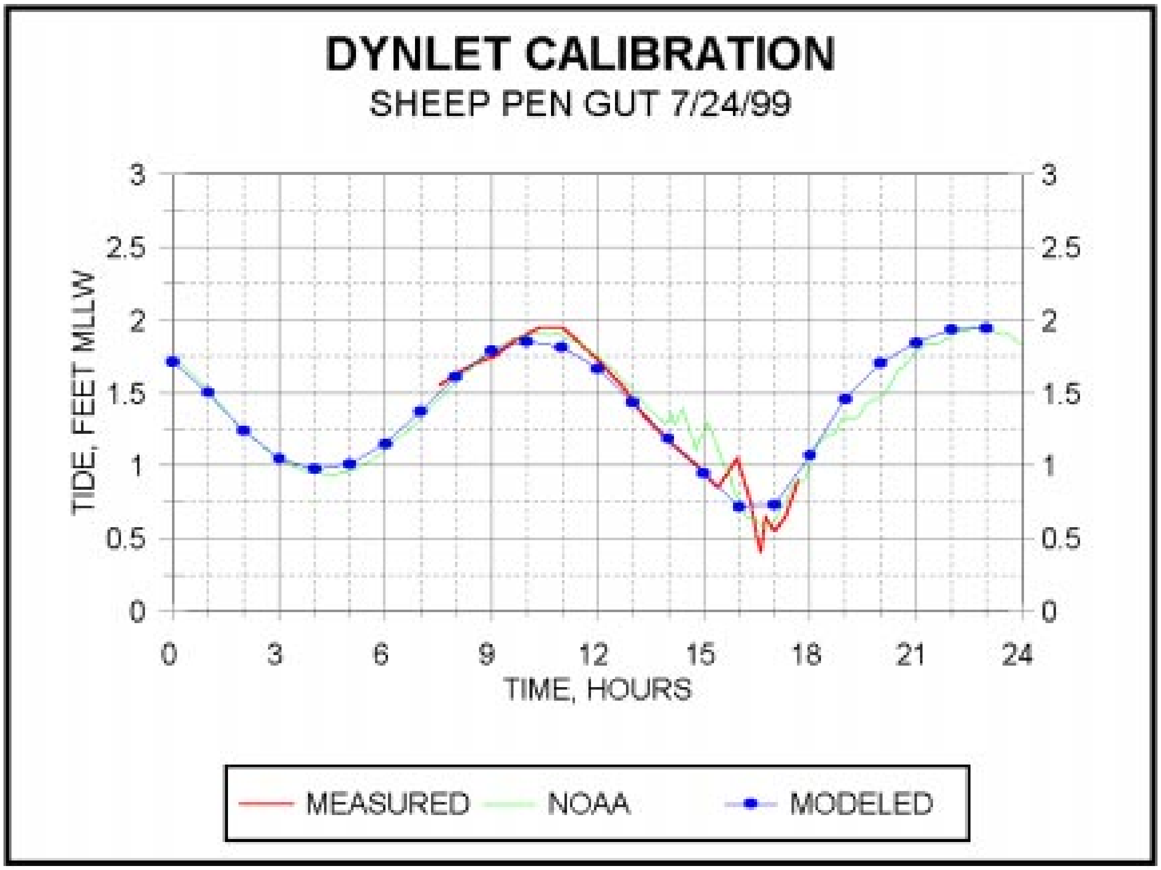
Hydrodynamic Numerical Modeling

A series of numerical tidal current models were set up to simulate the tidally driven currents in Sheep Pen Gut and in the near-shore region of Chesapeake Bay near the mouth of Sheep Pen Gut. The models include the one-dimensional flow model DYNLET, set up over a large area of the bay, which was used to provide boundary conditions for the near shore model. For the near shore region, the two-dimensional flow model TWO-D was used to examine the details of flow near the mouth of Sheep Pen Gut.

The DYNLET model was driven with NOAA measured tide time histories from Windmill Point to the south, and Solomons Island to the north. The channels through Smith Island, including Sheep Pen Gut, were simulated by a simplified channel system in the DYNLET model.

The DYNLET model was calibrated using tide and current measurements taken over a tide cycle at the mouth of Sheep Pen Gut for this project on 24 July 1999. The tide elevations measured at the mouth of Sheep Pen Gut, NOAA tide measurements from Lewisetta on the Western shore of the Chesapeake Bay, and the calibrated DYNLET model at the mouth of Sheep Pen Gut are shown in Figure 3.

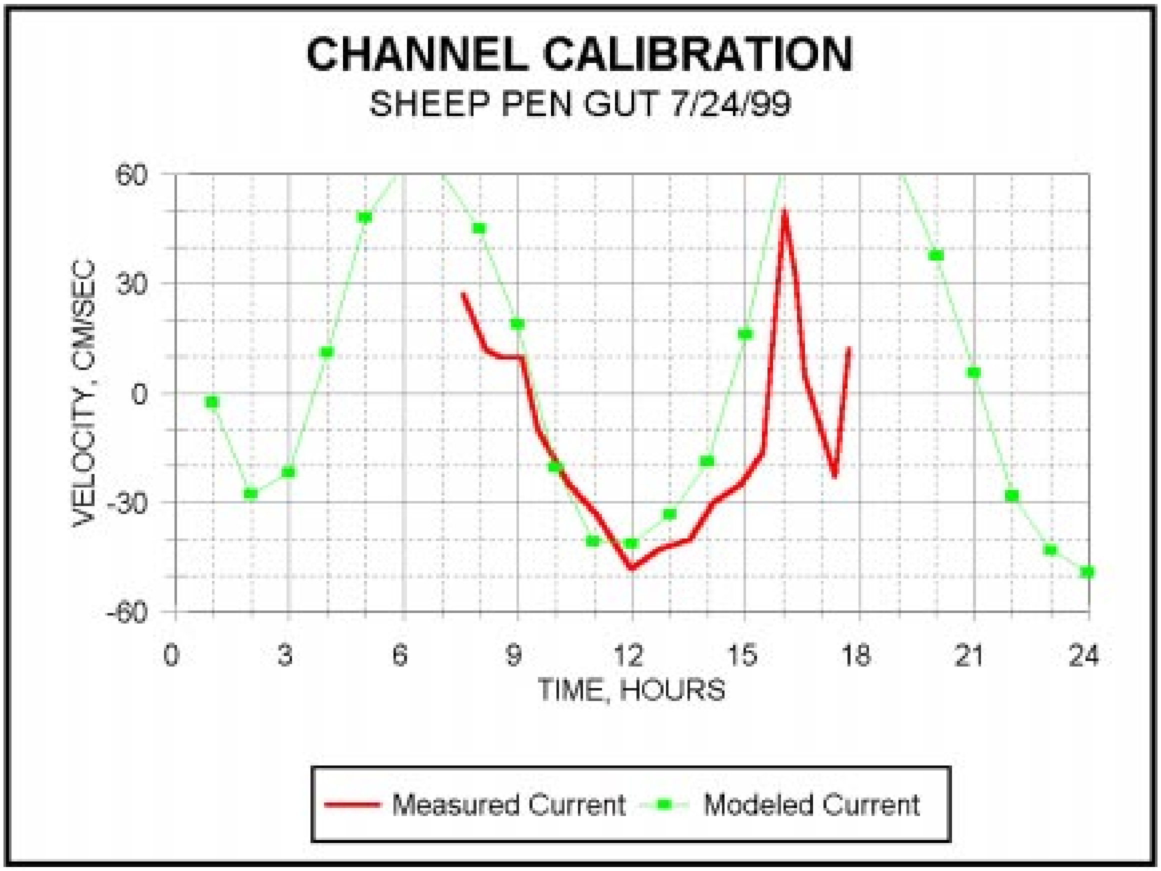
Figure 3 - DYNLET TIDE CALIBRATION



The irregular signal in the NOAA measurements and the Sheep Pen Gut measurements are due to a front moving through the measurement area from west to east, accompanied by strong winds. The strong winds and pressure changes apparently caused the Bay to slosh, first affecting the western shore at the NOAA Lewiston Gage, and then the Sheep Pen Gut measurement area. Nevertheless, the calibrated tidal signal shows excellent agreement with the measurements.

The measured currents at the mouth of Sheep Pen Gut were also compared with the DYNLET model results, shown in Figure 4.

Figure 4 - DYNLET CURRENT CALIBRATION



The impact of the passing front was more dramatic for the tidal currents than for the tidal elevations. While the ebb tide velocities are well behaved and well simulated by the DYNLET model, during the flood tide the measured current direction temporarily reversed and began flowing out of the gut. The model did not simulate this event because it was local, and not reflected in the boundary conditions further north and south in the bay. However, based on the good tidal elevation calibration and the good ebb current simulation, it is believed that a good calibration of the DYNLET model was achieved.

SHORELINE AND SEDIMENT TRANSPORT PROCESSES

Existing Shoreline

The existing shoreline generally consists of low, irregular, eroding marsh edge, with pockets of small sandy beaches. Behind the shoreline small, discontinuous sand dunes exist. Behind the sand dunes lie low marshes. The eroding marsh edge often has a vertical face, dropping to the silty, sandy bay bottom. In some areas where a confining headland offers protection, more extensive sand beaches exist, although the sand layer overlaying the marsh is typically thin.

In some areas open guts through the marsh are exposed to the bay by overwash through the low dunes, or by cuts through the marsh shoreline.

Historic Erosion Rates

For marsh islands such as Smith Island, land loss occurs through edge erosion and interior degradation. Edge erosion occurs when chunks of marsh peat are undermined by normal daily wave energy and are subsequently broken off by waves which occur during small storms, causing a horizontal recession. During larger storms, the storm surge may actually overtop the marsh allowing the wave energy to dissipate across the marsh surface rather than at the edge. The larger storms may actually cause less erosion.

Based upon historical shoreline change data developed by the Maryland Geological Survey, the southern shoreline of Tylerton has been eroding at a rate of less than 2 feet per year. These rates were based on a comparison of shoreline positions in 1849 and 1942. The barrier island west of the community of Rhodes Point has generally been eroding at a rate of 4 to 8 feet per year with some areas experiencing rates as high as 10 feet per year.

No data are available from the MGS concerning erosion rates along the Swan Island shoreline. However, the north jetty of Big Thorofare was recently detached from the mainland and remedial measures were necessary. In addition a large breach exists through the barrier just to the north of the Thorofare. A study conducted by the Virginia Institute of Marine Sciences VIMS in the late 70's indicated that the erosion rate along the Swan Island shoreline from the jetties to the Martin Wildlife Refuge were on the order of 8.5 feet per year.

Several coves and formerly enclosed areas are located on the north end of the island. Historically, spits of land protected the coves providing quiescent waters in the lee of the spits. As these spits have disappeared, the marsh shorelines of the coves are more susceptible to erosion and degradation. Data recently obtained from MGS indicate the erosion rate of the north end of the island to generally be on the order of 8 to 10 feet per year.

Sediment Transport

Analysis of the wind records indicates that the wave driven sediment transport is fairly evenly split between transport to the south and transport to the north, with transport to the south exceeding transport to the north by about 12 percent. This is based on an analysis of winds in the northwest and southwest quadrants that contribute to wave generation and wave driven transport along the western shoreline of Smith Island. Actual wave driven transport quantities will depend on the availability of sand sized particles in the nearshore area, orientation of the local shoreline, and local wave refraction effects.

Analysis of surveys of the offshore navigation channel at Sheep Pen Gut indicates that about 6 cubic yards/year/foot of material is trapped by the channel, leading to infilling rates of 2 to 3 feet per year for the years immediately following dredging. Over the 1500-

foot length of the channel this is equal to 9000 cubic yards per year for the offshore region of the bar. This figure does not include the transport along the shoreline.

Sea Level Rise

Based on long-term records (100 years) at Baltimore, Maryland, the rate of sea level rise is approximately 3.5 mm (.011 feet) per year. Local sea level rise has been documented to be about .013 feet per year and .012 feet per year at Atlantic City, New Jersey and Norfolk, Virginia, respectively. The Baltimore value is generally accepted as the current rate of rise in the Chesapeake Bay region. Assuming that this rate continues, at the end of the project life of 25 years, the total sea level rise would be about 3 inches. This rate of change is deemed to be within the uncertainty associated with the design methodologies, data measurements and construction procedures, and did not influence the design of the protective structures.

SECTION 3

Surveying and Mapping Requirements

Surveys and mapping for the Smith Island Feasibility Study were obtained in 1998 and 1999. Engineering Division provided a survey and mapping scope of work to Operations Division. Operations then contracted with 3DI, an aerial photography firm, who provided aerial photos and photogrammetric mapping for each of the Smith Island project areas. Operations Division surveyors set ground targets and control for all mapping and obtained hydrographic surveys around Smith Island. Operations then compiled all mapping and provided it to Engineering. This mapping is depicted on Sheets 3 to 16. Sheet 1 contains a map of all Smith Island with a plan legend – the area covered by each plan sheet.

Basic Data on the mapping:

- Vertical Datum: Mean Lower Low Water (MLLW) for the 1960 to 1978 tidal epoch
  Horizontal Datum: North American 1983, Maryland State Plane Coordinate System

- Scale: 50 scale mapping (1" = 50') and 1 foot contour interval
  Note – Base mapping provided by Operations was shown at 100 scale due to the large mapping areas

- Miscellaneous – Negative scale for the aerial photography was 1" = 350'. Soundings were obtained using a Starlink Global Positioning System and an Innerspace Depth Sounder.

- Survey Dates and Coverage:

Area	Date Aerial Photos	Date Hydro Survey	Coverage
Swan Island & Western Shoreline	Aug 1998	Sep 1998	1.5 mi of shoreline (100+ ft wide) from Swan Is extending north Hydro 1000 ft offshore
Fog Point Cove	Aug 1998	Oct 1998	0.7 mi of shoreline (100+ ft wide) Hydro 6000 ft along shoreline, out 1500+ ft from shore
Back Cove	Aug 1998 & Feb 1999	Sep 1998	950 acres incl. extensive shoreline & hydro in cove, 250 ft wide swath along shore
Terrapin Sand Cove	Feb 1999	Oct 1998	Hydro for 300 acre acres around Terrapin Point Islands
Sheep Pen Gut	**Aug 1998**	Jul 1998	0.5 mi of shoreline (300+ ft wide) from north end of geotextile tubes to north of Sheep Pen Gut Hydro 300+ ft offshore
Tylerton	Mar 1997	Aug & Sep 1998	200 ft wide swath along shoreline Hydro out 200 ft from shoreline
Ewell	Mar 1997	Aug 1998	0.8 mi of shoreline (200 ft wide) Hydro along 0.4 mi of west shore out

			700 ft

Note: Mapping for Sheep Pen Gut, Tylerton, Ewell was obtained as part of the Feasibility Study; however, projects in these areas will be constructed under separate authorities. As such, mapping for these areas is not included in this report.

Airborne Spectral Images were taken for Fog Point and Back Coves in October 1998 by 3DI. These images, taken from an airplane, show the two coves with different landforms and vegetation represented by different colors. Of particular interest was the extent of submerged aquatic vegetation (SAV) shown on these images. 3DI identified small areas of SAV along the shoreline of Fog Point Cove (Refer to Sheet 17, numbers 1 through 9 correspond to SAV beds). Large areas of SAV were found throughout Back Cove (Sheet 18). These images provide a snapshot of the SAV coverage in both coves. Ground truthing was not performed to verify the extent and type of SAV depicted on the spectral images.

SECTION 4

Geotechnical Investigations

General: Several sets of geotechnical investigations were performed throughout the feasibility study for the Smith Island Environmental Restoration Project. These investigations were performed to determine foundation conditions for potential offshore structures and to identify potential offshore borrow material sources. Laboratory testing was performed on selected samples obtained from the investigations in order to quantitatively assess the material properties. Based on the investigations completed to date, several potential offshore borrow areas have been identified, and no unsuitable foundation conditions have been identified. During PED phase, additional drilling will be required to fully investigate foundation conditions along the final alignment of any proposed structures. Additionally, more borrow investigations may be required depending on the environmental constraints attached to the potential sites identified to this point.

Offshore Borrow Material Investigation: An initial borrow material investigation offshore of Smith Island was undertaken from November 9-15, 1998. A grid was developed to determine potential borrow sites. The grid consisted of 81 holes spaced at 2000-foot centers in various offshore areas, avoiding known Oyster beds. Determining subsurface soil conditions of the selected offshore areas consisted of driving a 4-foot split-spoon at fixed intervals. If sand was recovered in the bottom of the spoon, the split-spoon was advanced to a depth of 10 feet. Refer to Sheet 2 for a map depicting hole locations.

Five areas were investigated—

1. South of the Big Thorofare Jetties, West of Rhodes Point.
2. North of the Big Thorofare Jetties, West of Swan Island.
3. North of the Martin Wildlife Refuge.
4. East of the Martin Wildlife Refuge.
5. Area around Big Thorofare Channel, East of jetties, near Ewell.

A total of 56 holes were finished during the week given for the drilling. Twelve (12) holes were finished in area 1, thirteen (13) holes in area 2, twelve (12) holes in area 3, eight (8) holes in area 4, and eleven (11) holes in area 5. These holes are enough to get a good estimate on where potential borrow areas exist. Suitability of borrow material as geotextile tube fill is discussed in the following paragraphs. However, at this time, it does not appear that geotextile tubes will be used for this project.

Area 1 generally consisted of fine sand and silt. The sand ranged in depth from 0.0' – 10.0'+ in this area. Some borings did not encounter sand. These encountered mostly silt with some clay. One boring encountered a thin layer of medium to coarse sand. This is an exception in Area 1. Depending on grain size requirements for the potential projects, Area 1 is a marginal borrow source candidate. The sand found is most likely too fine for use in the geotextile tubes. However, if elevation is not a critical issue for certain geotextile tubes, and the wave climate is not very rough, fine sand could be used for geotextile tube fill. Area 1 material could be used for wetland fill if adequately protected from wave action.

Area 2 generally consisted of a layer of fine sand ranging in depth from 4 feet to deeper than 10 feet. Several borings, however, recovered only clay. Depending on necessary grain size for the potential projects, area 2 is a borrow source candidate. Fine sand is not ideal for geotextile tubes. However, depending on the geotextile tubes' purpose, fine sand may be adequate. Area 2 material could be used for wetland fill if adequately protected from wave action.

Area 3 generally consisted of fine sand, silt, and clay. Areas where sand was found were usually no deeper than 5 feet. Clay was found in many holes, some at the top of the hole, to more typically, 5 feet below ground surface. This area is very similar to Area 1. This could be considered a marginal borrow source candidate. The sand found is most likely too fine for use in the geotextile tubes. However, if elevation is not a critical issue for certain geotextile tubes, and the wave climate is not very rough, fine sand could be used for geotextile tube fill. Area 3 material could be used for wetland fill if adequately protected from wave action.

Area 4 generally consisted of a fine sandy silt. This would not be considered as a borrow source for geotextile tubes. It may be considered a suitable borrow source for wetland fill, depending on the fill requirements.

Area 5 generally consisted of a thin 2-inch layer of fine sand above at least a 5-foot layer of clay. Thus, area 5 has been eliminated from consideration as a borrow source.

If a borrow source is chosen, the next phase would include a more in-depth investigation of the selected borrow area. A thorough delineation of oyster beds, SAV areas, and other environmentally sensitive features would be required. The next phase would also help get a much more accurate estimate on potential borrow quantities.

The recommendation from this initial borrow exploration is to further explore Area 2 as a potential borrow source. A more accurate estimate on limits and quantities can be obtained from the next drilling phase. Also, depending on grain size requirements, Area 1 and Area 3 can also be further explored as a potential borrow source. To be used as wetland fill, adequate protection must be provided from wave action.

Very rough quantity estimates were calculated from the available data for Areas 1-3:

- Area 1 – approximately 2.2 million cubic yards of usable material (Sand and silty sand)

- Area 2 – approximately 2.5 million cubic yards of usable material

- Area 3 – approximately 1.4 million cubic yards of usable material

Depending how much material is allowed to be borrowed, up to 4000 acre-feet of material is potentially available. The estimates were made assuming total removal of all usable material. In reality, the creation of large holes would not be allowed. A method of removing material in strip-like fashion would most likely be required, thus reducing the potential borrow amounts significantly. However, the reduction factor is not known at this time, so total usable material is the estimate given.

Discussions with National Marine Fisheries Service (NMFS) were undertaken after the initial borrow investigations, regarding potential restrictions on borrow areas. John Nichols, NMFS, stated that borrow material taken from nearshore areas would be preferable at Smith Island. He stated that all other potential options for borrow material need to be shown as not viable before NMFS would approve the use of offshore material. Nearshore samples were not collected during this initial borrow investigation. A sandbar can be seen close to the western shoreline along the Martin Wildlife Refuge. The area just north of the Big Thorofare Jetties would likely also include sand. However, these two options have not been explored yet. It is suggested that if NMFS requires nearshore borrow, additional investigations be undertaken to determine the nature and extent of potential borrow material in the approved areas.

Rhodes Point Jetty Investigations (Sheep Pen Gut): Between 9/24/98 and 10/07/98, nineteen (19) holes were drilled near the existing federal channel at Sheep Pen Gut, on the western coast to investigate foundation conditions for a potential realignment of the channel and potential jetty to the north of the new channel. The drilling effort also included investigation of foundation conditions for a potential erosion protection structure south of the new channel. Drill holes were performed to depths of 26.5 feet for structure foundation holes. Channel foundation holes were drilled to depths of 11.5 feet.

The three drill holes for the erosion protection structure found layers of sand and silt generally to a depth of 16 feet, underlain by a soft lean clay layer to the bottom of the hole. The foundation conditions are thought to be suitable for placement of a structure. Undisturbed samples should be obtained for performing a settlement analysis, but most likely the structure would only need to be overbuilt, not relocated.

The eight drill holes for the potential realignment of the federal channel show mostly a sandy silt material, occasionally interspersed with clay lenses. This material is only proposed to be dredged, and dredging this material appears feasible.

The eight drill holes for the potential jetty north of the proposed channel realignment generally show a sandy silt material overlying a soft clay. The thickness of the clay layer varies from 8 feet to unknown depths continuing past the bottom of the drill hole. As with the erosion protection structure, this foundation material does not appear to be unsuitable. Undisturbed samples should be obtained for performing a settlement analysis, but most likely the structure would only need to be overbuilt, not relocated.

Since the initial phase of drilling was performed, a twin-jetty alignment has been recommended. In this alignment, the north jetty has a slightly different alignment. Additional drilling and testing will be required in the next design phase to finalize the foundation design for the north jetty and complete the foundation design for the south jetty. Undisturbed samples will be required in order to estimate settlement of any structure.

Additional Foundation Exploration: Additional foundation drilling was performed at certain points around the Martin Wildlife Refuge. These drill holes were located at places where there is a high potential for some sort of structure to be placed (i.e. breakwater, stone sill). This drilling effort was intended to be an initial assessment of potential foundation conditions at various points in the project area. A more extensive foundation exploration will be required once final locations for various structures are located.

Much like the previous foundation exploration drill holes, these drill holes did not encounter any conditions that would be considered unsuitable. Generally, a sandy silt was found above a soft clay layer. The clay layer generally was located about 15 feet below the Bay surface. The thickness of the clay layer varied, but the bottom was generally located at or below the bottom of the drill hole.

Using consolidation test information from the Poplar Island Project, settlement of the layers encountered varied depending upon layer thickness, but was generally between 6”-12” for a stone structure built to elevation +4 MLLW. Poplar Island test information was chosen because the clays there had similar blow counts and were located near an eroding island in the Chesapeake Bay as well. During the next phase of drilling, undisturbed samples will be required, and consolidation tests will need to be performed in order to estimate potential settlement.

Refer to Sheets 3 through 14 for drill hole locations taken in the various project areas.

Geotechnical Design Requirements: For both breakwaters and jetties that may be used on this project, several features will be required. A high strength geotextile will be required under any jetty or breakwater that is constructed. The geotextile will minimize local shear failures and excessive differential settlement by distributing the loads from the structures more uniformly and by adding some tensile strength to the foundation. A minimum of 6” overbuild will be required for any breakwater or jetties as well, depending on the results from the next set of subsurface investigations. This is to account for potential settlement and other construction uncertainties. If the next investigations show the potential for more than 6” of settlement, then a larger overbuild may be required.

Future Geotechnical Analyses Required: In the final design phase, additional drilling, testing, and analyses will be required. Due to the shift in the alignment of the Rhodes Point jetties, and the addition of one jetty, additional drilling and testing will be required for foundation analysis. Additional drill holes will be required, and undisturbed samples will be required in order to perform consolidation lab tests for determining potential settlement. Also, the final locations of the structures around Martin Wildlife Refuge will need to be drilled to determine the foundation conditions for design. Settlement for these structures will also need to be estimated. Necessary foundation design, including geotextile design, will be performed. Additional borrow exploration and analysis will be required to determine if there is suitable material obtainable for placement behind offshore erosion protection structures. Current borrow material exploration and analysis is not adequate to definitively identify adequate sources of borrow material. The borrow sources must also be approved by the appropriate resource agencies. Specifications will be written for appropriate areas of work, such as stonework and geotextile.

SMITH ISLAND, MD.
ENVIRONMENTAL RESTORATION

SUBSURFACE EXPLORATION NOTES

1. EXPLORATION WAS PERFORMED DURING SEPTEMBER & OCTOBER 1998.

2. DRILL HOLES (DH) WERE ACCOMPLISHED BY STANDARD PENETRATION TEST PROCEDURE (SPT) USING A 1-3/8"ID SPLIT SPOON SAMPLER. SAMPLE SPOONS WERE ADVANCED BY A 140# HAMMER FALLING 30". THESE HOLES WERE ADVANCED BETWEEN SAMPLES BY JETTING THE 4" ID STEEL CASING TO THE TOP OF THE NEXT SAMPLE INTERVAL. BLOW COUNTS SHOWN ARE FOR 0.5' OF DRIVE, UNLESS OTHERWISE INDICATED.

   WH - DENOTES WEIGHT OF HAMMER

   WR - DENOTES WEIGHT OF ROD

   ALL BORINGS WERE DRILLED IN THE CHESAPEAKE BAY BY A TRIPOD RIG MOUNTED ON A BARGE. DEPTH OF BAY WATER AT EACH BORING LOACATION WAS DETERMINED BY SOUNDING THE BAY USING A WEIGHTED MEASURING TAPE PRIOR TO START OF SAMPLING. THESE DEPTHS WITH TIME ARE SHOWN AT THE BOTTOM OF EACH LOG.

3. BLOW COUNTS REQUIRED TO ADVANCE SAMPLE SPOON ARE SHOWN IN COLUMN (a).

4. SOIL DESCRIPTIONS ARE SHOWN IN COLUMN (c).

5. SOIL DESCRIPTIONS ARE LABORATORY CLASSIFICATIONS BASED ON THE UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM D2487/2488).

   THE ORGANIC TEST (ASTM D 2974, METHOD "C"; OR LOSS ON IGNITION TEST (LOI) (AASHTO-T-267) WAS USED TO EVALUATE AND DESCRIBE THE ORGANIC CONTENT OF SOILS FOR DESIGN AND CONSTRUCTION AS FOLLOWS:

LOI	SOIL DESCRIPTION
<12	INORGANIC
12 TO 24	ORGANIC
25 TO 60	VERY ORGANIC
>60	PEAT (Pt)

6. FOR LOCATIONS OF SUBSURFACE EXPLORATIONS, SEE BORING LOCATION PLAN.

STA.	ENVIRONMENTAL RESTORATION	N	DH-1
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	October 7, 1998

DEPTH(ft)	(c)	(d)	Depth scale	(a)	(b)
0.4	Wet, gray, sandy{fine} SILT w/ tr. shell fragments (ML)			WR-1-1	
4.5	Moist, lt. gray, lean CLAY w/ fine sand & tr. mica (CL)			1-4-4	
7.0	Very moist, lt. gray, sandy{medium.-fine} SILT (ML)		5	2-2-2	
9.5	Wet, lt. olive gray, silty medium-fine SAND w/ tr. mica (SM)			2-1-2	
11.0	Wet, gray, silty medium-fine SAND w/ tr. mica (SM)		10	3-2-3	
12.0	Wet, lt. gray, poorly graded medium-fine SAND w/ silt & tr. mica (SP-SM)				
16.3	Wet, gray, poorly graded medium-fine SAND w/ silt & tr. mica (SP-SM)		15	3-6-8 3-3-2	
18.4	Very moist, gray, lean CLAY w/ sand & tr. mica (CL)			1-1-1	
19.5	Wet, gray, sandy(medium-fine) lean CLAY w/ tr. shell fragments (CL)				
22.0	Wet, olive gray, clayey medium-fine SAND w/ tr. shell fragments (SC)		20	1-2-1	
24.5	Very, moist, gray, sandy(medium-fine) lean CLAY w/ tr. shell fragments (CL)			1/1.5'	
26.5	Moist, gray, fat CLAY w/ sand (CH)		25	2-3-2	
	BOTTOM OF HOLE		30		
	Depth of bay water 3.75' @ start of boring - 0930 Hrs.		35		

DH-1
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill | Auger | SPT | RB | Cored

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.
SHEEP PEN GUT

N
E
COMPLETED: October 7, 1998

DH-2

DEPTH(ft)	(c)	(d)	(a)	(b)
	Very moist, lt. olive brown, silty fine SAND w/ tr. mica (SM) w/ tr. organics		WR-2-5	
2.0	Very moist, reddish brown, silty fine SAND w/ tr. mica (SM)		3-2-3	
4.5	Wet, lt. reddish brown, silty fine SAND w/ tr. mica (SM)		3-2-3	
			2-5-5	
9.5	Moist, gray, poorly graded medium-fine SAND (SP)		5-4-2	
10.8	Very moist, dk. gray, silty fine SAND w/ tr. mica (SM)			
12.0	Moist, gray, silty medium-fine SAND w/ tr. mica (SM)		4-2-4	
14.5	Wet, gray, lean CLAY w/ fine sand (CL)		5-5-5	
15.7	Moist, gray, poorly graded fine SAND w/ silt (SP-SM)			
17.0	Wet, gray & olive gray, clayey medium-fine SAND (SC)		WR/.75'-1/.75'	
19.5	Wet, gray & olive gray, clayey medium-fine SAND w/ tr. shell fragments (SC)		1-1-1	
22.0	Moist, greenish gray, fat CLAY w/ sand (CH)		1-1-2	
			5-6-9	
26.5	BOTTOM OF HOLE			

Depth of bay water 4.75' @ start of boring - 1124 Hrs.

DH-2
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:30

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.
SHEEP PEN GUT

N
E
COMPLETED: October 7, 1998

DH-3

DEPTH(ft)	(c)	(a)
1.0	Wet, dk. grayish brown sandy{fine} lean CLAY (CL)	WR/1.0'-1
2.0	Moist, grayish brown, sandy{fine} lean CLAY (CL) w/ organics	
4.5	Very moist, gray, sandy{fine} lean CLAY (CL)	2-2-4
5.6	Moist, lt. olive gray, sandy{fine} lean CLAY (CL)	3-6-7
7.0	Wet, lt. gray to yellowish brown, silty medium-fine SAND (SM)	
12.0	Wet, gray, poorly graded medium-fine SAND w/ silt & tr. mica (SP-SM)	5-6-7 4-9-9
14.5	Wet, dk. gray, poorly graded medium-fine SAND w/ silt & tr. mica (SP-SM)	3-5-3
15.9	Wet, dk. grayish brown, poorly graded fine SAND w/ silt & tr. mica (SP-SM)	3-2-1
17.0	Very moist, olive gray, lean CLAY w/ sand (CL)	
19.5	Wet, gray, clayey medium-fine SAND w/ tr. shell fragments (SC)	1/.75'-1/.75'
22.0	Wet, olive gray, sandy{medium-fine} fat CLAY w/ tr. shell fragments (CH)	3-1-1
24.5	Moist, gray, sandy fat CLAY (CH)	3-2-2
26.5	Wet, dk. grayish brown, clayey medium-fine SAND (SC)	2-3-3

(d) (b)

Depth scale: 5, 10, 15, 20, 25, 30, 35

BOTTOM OF HOLE

Depth of bay water 4.75 @ start of boring - 1403 Hrs.

DH-3
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.	ENVIRONMENTAL RESTORATION	N	DH-4
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	September 24, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
0.5	Wet, grayish brown, silty fine SAND (SM) w/ shell fragments		WR-1-1	
4.5	Wet, very dk. gray, silty fine SAND w/ tr. organics (SM)		WH/1.5'	
5.5	Wet, grayish brown, sandy{fine} SILT (ML)		WH/1.5'	
9.5	Wet, dk. gray silty medium-fine SAND (SM)		WR-1-1	
11.5	Wet, gray, poorly gradedmedium-fine SAND w/ silt (SP-SM)		2-4-5	

BOTTOM OF HOLE

Depth of bay water 7.67' @ start of boring - 1308 Hrs.

5
10
15
20
25
30
35

DH-4
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.	ENVIRONMENTAL RESTORATION	N	DH-5
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	September 30, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Very moist, gray & black, poorly graded fine SAND w/ silt (SP-SM)		1-3-4	
3.4	Very moist, gray, poorly graded fine SAND w/ silt (SP-SM)		2-2-1	
4.5	Moist, reddish gray, lean CLAY w/ tr. fine sand (CL)			
7.0	Moist, gray, silty fine SAND (SM)		3-4-3	
9.5	Wet, brown, silty fine SAND (SM)		3-6-11	
11.0	Moist, grayish brown, poorly graded fine SAND w/ silt (SP-SM)		8-4-3	
11.5	Very moist, sandy{fine} lean CLAY (CL)			

BOTTOM OF HOLE

Depth of bay water 2.67' @ start of boring - 1335 Hrs.

5 10 15 20 25 30 35

DH-5
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:31

STA.	ENVIRONMENTAL RESTORATION	N	DH-6
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	October 7, 1998

DEPTH(ft)	(c)	(d)		(a)	(b)
2.0	Moist, dk. grayish brown, poorly graded SAND w/ silt (SP-SM)			WR-3-2	
4.5	Very moist, very dk. gray & brown, sandy{fine) lean CLAY w/ tr. mica (CL)			5-2-1	
7.0	Very moist, lt. gray & lt. olive brown, sandy{fine) lean CLAY w/ tr. mica (CL)		5	2-3-4	
9.5	Very moist, brown, poorly graded fine SAND w/ silt (SP-SM)			6-8-9	
11.5	Wet, gray & yellowish brown, poorly graded fine SAND w/ silt (SP-SM)		10	3-6-6	
	BOTTOM OF HOLE				
	Depth of bay water 3.50' @ start of boring - 1710 Hrs.		15		
			20		
			25		
			30		
			35		

DH-6
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.	ENVIRONMENTAL RESTORATION	N	DH-8
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	October 6, 1998

DEPTH(ft)	(c)	(d)		(a)	(b)
	Wet, dk. gray, silty fine SAND (SM)			WR-2-2	
2.0	Wet, brown yellow to gray, silty fine SAND (SM)			4-3-3	
4.5	Wet, lt. yellowish brown, silty fine SAND (SM)		5	5-2-4	
7.0	Wet, lt. brownish gray, silty medium-fine SAND (SM)			4-3-2	
9.5	Wet, gray, poorly graded medium-fine SAND w/ silt (SP-SM)		10	2-3-5	
11.5	BOTTOM OF HOLE				
	Depth of bay water 4.75' @ start of boring - 1701 Hrs.		15		
			20		
			25		
			30		
			35		

DH-8
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:31

STA.	ENVIRONMENTAL RESTORATION	N	DH-9
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	October 6, 1998

DEPTH(ft)	(c)	(d)	Depth	(a)	(b)
2.0	Wet, dk. gray, silty fine SAND (SM)			2-2-4	
4.5	Wet, lt. brown gray, silty fine SAND (SM)			3-3-4	
7.0	Wet, lt. yellowish brown, silty fine SAND (SM)		5	4-6-9	
9.5	Wet, lt. gray, poorly graded medium-fine SAND w/ silt (SP-SM)			3-4-5	
11.5	Very moist, grayish brown sandy fine SILT (ML)		10	2-1-2	
	BOTTOM OF HOLE				
	Depth of bay water 5.00' @ start of boring - 1613 Hrs.		15		
			20		
			25		
			30		
			35		

DH-9
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:32

STA.	ENVIRONMENTAL RESTORATION	N
OFFSET:	SMITH ISLAND, MD.	E
TOP ELEV:	SHEEP PEN GUT	COMPLETED: September 24, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
0.5	Wet, dk. gray, silty fine SAND w/ tr. of gravel and shell fragments (SM)		1-3-3	
2.0	Wet, gray, silty fine SAND (SM)			
	Wet, lt. yellowish brown, silty fine SAND (SM)		3-4-6	
		5	3-4-2	
7.0	Very moist, dk. gray, sandy{fine} SILT (ML)		2-1-4	
9.5	Wet, lt. brownish gray, silty medium-fine SAND w/ tr. shell fragments (SM)	10	2-5-3	
10.5				
11.5	Wet, grayish brown sandy{medium-fine) SILT (ML)			
	BOTTOM OF HOLE			
	Depth of bay water 6.83' @ start of boring - 1423 Hrs.	15		
		20		
		25		
		30		
		35		

DH-10
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.
SHEEP PEN GUT

N
E
COMPLETED: September 29, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Very moist, yellowish brown, silty fine SAND (SM)		2-1-1	
4.5	Very moist, gray, silty fine SAND (SM)		3-6-7	
7.0	Moist, dk. grayish brown, SILT w/ tr. fine sand (ML)		3-3-2	
9.5	Moist, weak red, lean CLAY w/ fine sand (CL)		2-2-1	
11.5	Moist, weak red, sandy(fine) lean CLAY (CL)		1-2-1	

BOTTOM OF HOLE

Depth of bay water 9.17' @ start of boring - 1611 Hrs.

5
10
15
20
25
30
35

DH-11
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:32

STA.	ENVIRONMENTAL RESTORATION	N	DH-14
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	October 6, 1998

DEPTH(ft)	(c)	(d)	Depth	(a)	(b)
0.4	Wet, very dk. brown, very organic silty SAND w/ roots (SM) L.O.I. = 50.2% - Very organic			WR/1.0'-WH/0.5'	
2.0	Wet, gray, lean CLAY w/ tr. fine sand & tr. roots (CL)				
	Moist, gray & yellowish brown, lean CLAY w/ tr. fine sand & tr. roots (CL)			1-1-1	
4.5	Moist, gray & yellowish brown, lean CLAY w/ tr. fine sand (CL)		5	5-6-9	
8.0	Very moist, dk. gray, clayey SAND w/ tr. mica (SC)			7-10-10	
8.3	Moist, gray, poorly graded medium-fine SAND w/ silt (SP-SM)		10	6-7-8	
				5-9-8	
			15	6-5-6	
17.0	Very moist, dk. greenish gray, clayey coarse-fine SAND w/ tr. gravel (SC) w/ tr. shell fragments			1-1/1.0'	
19.5	Wet, dk. greenish gray, clayey coarse-fine SAND w/ tr. gravel & shell fragments (SC)		20	2-2-1	
22.0	Very moist, gray, fat CLAY w/ sand (CH)			1-1-1	
24.5	Wet, gray, silty coarse-fine SAND w/ tr. gravel & shells (SM)		25	3-4-13	
26.5	BOTTOM OF HOLE				
	Depth of bay water 5.17' @ start of boring - 1350 Hrs.		30		
			35		

DH-14
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:33

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.
SHEEP PEN GUT

N
E
COMPLETED: October 6, 1998

DEPTH(ft)	(c)	(a)
0.3	Very moist, dk. gray, poorly graded SAND w/ tr. mica (SP)	WR-1/1.0'
2.0	Very moist, gray, lean CLAY w/ tr. sand & roots (CL)	
4.5	Moist, gray, lean CLAY w/ sand & tr. roots (CL)	WR-1-4
9.5	Very moist, gray & olive brown, sandy{fine} lean CLAY (CL)	5-8-9 4-6-5
12.0	Very moist, gray & olive brown, silty medium-fine SAND (SM)	2-3-3
14.5	Moist, dk. gray, silty medium-fine SAND (SM)	2-2-3
17.0	Moist, gray, poorly graded medium-fine SAND w/ tr. mica (SP)	4-6-5
17.9	Moist, dk. brownish gray, silty medium-fine SAND (SM)	
19.5	Very moist, greenish gray, sandy(fine) lean CLAY (CL)	3-3-4
22.0	Wet, greenish gray, sandy(coarse-fine) lean CLAY w/ tr. shell fragments (CL)	1-1-1
24.5	Very moist, greenish gray, fat CLAY w/ tr. sand (CH)	1-1-1
26.5	Very moist, gray & dk. grayish brown, clayey coarse-fine SAND w/ tr. gravel (SC)	2-5-11

(d) (b)

Depth scale: 5, 10, 15, 20, 25, 30, 35

BOTTOM OF HOLE

Depth of bay water 3.75' @ start of boring - 1028 Hrs.

DH-15
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.	ENVIRONMENTAL RESTORATION	N	DH-16
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	October 6, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
1.5	Wet, dk. gray, poorly graded fine SAND (SP)		3-3-2	
4.5	Very moist, gray, sandy{fine} SILT w/ tr. shell fragments (ML)		WH-3-5	
7.0	Wet, olive, silty fine SAND w/ tr. mica (SM)	5	4-7-9	
9.5	Wet, olive gray, silty fine SAND w/ tr. mica (SM)		5-4-7	
12.0	Wet, gray, silty medium-fine SAND w/ tr. mica (SM)	10	3-7-9	
17.0	Wet, gray, silty fine SAND w/ tr. mica (SM)	15	2-2-2 3-3-1	
24.5	Wet, greenish gray, clayey SAND w/ shell fragments & tr. gravel (SC)	20	1-1-1 WR/1.0'-1 2-1-4	
26.5	Very moist, dk. gray, sandy fat CLAY (CH)	25	2-1-1	
	BOTTOM OF HOLE Depth of bay water 2.67' @ start of boring - 0836 Hrs.	30 35		

DH-16
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.	ENVIRONMENTAL RESTORATION	N	**DH-17**
OFFSET:	SMITH ISLAND, MD.	E	**1 of 1**
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	September 30, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Moist, very dk. gray & brown, poorly graded medium-fine SAND (SP)		WR/1.0'-3	
3.3	Moist, grayish brown, poorly graded fine SAND w/ silt (SP-SM)		WR-3-6	
3.6	Moist, gray & yellowish brown, sandy{fine} lean CLAY (CL)			
4.5	Very moist, grayish brown, silty fine SAND (SM)			
7.0	Very moist, gray & dk. yellowish brown, sandy{fine} SILT w/ tr. mica (ML)		5-6-6	
9.5	Very moist, gray, silty fine SAND (SM)		5-3-4	
10.6	Moist, gray & grayish brown, silty medium-fine SAND (SM)		2-4-2	
12.0	Very moist, dk. grayish brown sandy{fine} SILT (ML)			
14.5	Very moist, dk. gray, lean CLAY w/ fine sand (CL)		2-3-2	
17.0	Very moist, dk. gray & dk. grayish brown, lean CLAY w/ fine sand (CL)		WR/1.5'	
19.5	Wet, gray, clayey coarse-fine SAND w/ shell fragments (SC)		1-1-1	
22.0	Wet, gray & brown, sandy{coarse-fine} lean CLAY w/ shell fragments (CL)		1/1.0'-1	
24.5	Wet, gray, clayey coarse-fine SAND (SC) w/ shell fragments		1-1-1	
26.5	Very moist, greenish gray, fat CLAY w/ tr. sand (CH)		2-1-1	

BOTTOM OF HOLE

Depth of bay water 5.50' @ start of boring - 0956 Hrs.

DH-17
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill | Auger | SPT | RB | Cored

STA.	ENVIRONMENTAL RESTORATION	N	**DH-18**
OFFSET:	SMITH ISLAND, MD.	E	
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	September 25, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Wet, dk. gray, poorly graded fine SAND w/ silt, tr. gravel, mica & shell fragments (SP-SM)		2-1-1	
3.2	Moist, lt. gray, sandy{fine} SILT w/ tr. mica (ML)		1-5-3	
4.5	Wet, lt. gray, silty fine SAND w/ tr. mica (SM)			
7.0	Wet, gray, silty fine SAND w/ tr. mica (SM)		4-4-5	
9.5	Wet, gray, poorly graded fine SAND w/ silt & tr. mica (SP-SM)		2-3-4	
12.0	Very moist, gray, sandy{fine} SILT (ML)		5-3-4	
14.5	Very moist, gray, lean CLAY w/ fine sand (CL)		3-2-2	
19.5	Wet, greenish gray, clayey SAND w/ shell fragments & tr. gravel (SC)		WR-1-1 1-1-1	
24.5	Wet, greenish gray, silty SAND w/ shell fragments & tr. gravel (SM)		1-1-1 1-4-2	
26.5	Very moist, dk. gray, fat CLAY w/ fine sand (CH)		3-10-9	

BOTTOM OF HOLE

Depth of bay water 5.00' @ start of boring - 0906 Hrs.

DH-18
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill | Auger | SPT | RB | Cored

GEO-2 SMI02.GPJ 7/13/00 13:34

STA.	ENVIRONMENTAL RESTORATION	N	DH-19
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	September 29, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Wet, olive, sandy{fine} SILT (ML)		1-1-3	
3.4	Very moist, gray, sandy{fine} SILT (ML)		1-6-7	
4.5	Wet, lt. brownish gray, poorly graded fine SAND w/ silt (SP-SM)			
8.1	Wet, gray, poorly graded fine SAND w/ silt (SP-SM)		2-2-4	
9.5	Very moist, gray, SILT w/ fine sand (ML)		1-1-2	
12.0	Very moist, dk. gray, fat CLAY w/ sand (CH)		WR-1-1	
14.5	Wet, greenish gray, silty SAND w/ shell fragments (SM)		1-1-1	
17.0	Wet, lt. gray, silty SAND w/ shell fragments (SM)		1-1-1	
19.5	Wet, gray, silty SAND w/ shell fragments (SM)		2-2-2	
21.1	Wet, gray, poorly graded SAND w/ silt & shell fragments (SP-SM)		1-2-1	
22.0	Very moist, gray, sandy fat CLAY w/ tr. gravel & shell fragments (CH)			
22.9	Wet, gray, poorly graded SAND w/ shell fragments (SP)		3-6-10	
24.5	Wet, dk. gray brown, silty medium-fine SAND w/ shell fragments & tr. gravel (SM)			
25.7	Wet, gray, poorly graded medium-fine SAND w/ shell fragments (SP) w/ tr. fine gravel		5-10-15	
26.5	Wet, grayish brown, poorly graded medium-fine SAND w/ tr. gravel & mica (SP)			

BOTTOM OF HOLE

Depth of bay water 6.50' @ start of boring - 1300 Hrs.

DH-19
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:34

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.
SHEEP PEN GUT

N
E
COMPLETED: September 29, 1998

DH-20

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Very moist, dk. grayish brown, silty fine SAND (SM)		WR-1-3	
4.5	Very moist, yellowish brown, silty medium-fine SAND (SM)		4-4-5	
7.0	Moist, gray & brown, silty medium-fine SAND (SM)		3-5-6	
9.5	Moist, gray, micaceous SILT w/ tr. fine sand (ML)		2-2-3	
12.0	Moist, dk. gray, lean CLAY w/ fine sand (CL)		1-1-1	
14.5	Moist, dk. gray, lean CLAY w/ fine sand & tr. shell fragments (CL)		WR/1.5'	
17.0	Wet, dk. gray & dk. grayish brown, sandy{coarse-fine} lean CLAY w/ shell fragments (CL)		1-2-1	
22.0	Wet, gray, silty coarse-fine SAND w/ shell fragments & tr. gravel (SM)		WR-WH-1 1-2-1	
24.5	Very moist, sandy fat CLAY (CH)		1-1-2	
26.5	Moist, bown, poorly graded SAND w/ silt & tr. shell fragments (SP-SM) w/ tr. fine gravel		17-20-21	

Depth scale: 5, 10, 15, 20, 25, 30, 35

BOTTOM OF HOLE

Depth of bay water 6.92' @ start of boring - 0900 Hrs.

DH-20
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill · Auger · SPT · RB · Cored

STA.	ENVIRONMENTAL RESTORATION	N	**DH-21**
OFFSET:	SMITH ISLAND, MD.	E	**1 of 1**
TOP ELEV:	SHEEP PEN GUT	COMPLETED:	September 24, 1998

DEPTH(ft)	(c)	(a)	(b)
2.0	Moist, brown, silty fine SAND (SM)	3-3-5	
4.5	Wet, brown, sandy{fine) SILT w/ tr. mica (ML)	2-3-1	
7.0	Very moist, gray, silty fine SAND (SM)	3-4-4	
9.5	Moist, gray, sandy{fine} SILT (ML)	2-4-4	
12.0	Very moist, dk. gray, sandy{fine} lean CLAY (CL)	1-1-1	
14.5	Very moist, dk. gray & dk. grayish brown, sandy{fine} lean CLAY w/ shell fragments (CL)	WR-1-1	
17.0	Wet, gray & dk. grayish brown, clayey SAND w/ shell fragments & tr. gravel (SC)	WR-1-1	
19.5	Wet, brown, well graded SAND w/ silt (SW-SM) w/ shell fragments	2-2-1	
20.3	Wet, dk. gray, clayey coarse-fine SAND w/ tr. shell fragments (SC)		
22.0	Wet, gray & dk. grayish brown, sandy{coarse-fine} fat CLAY w/ tr. shell fragments (CH)	2-1-1	
24.5	Very moist brown, poorly graded SAND w/ tr. shell fragments (SP)	3-17-32	
25.4	Very moist, very dk. grayish brown, clayey SAND (SC-H)		
26.5	Very moist, poorly graded coarse-fine SAND w/ tr. shell fragments (SP)	4-3-7	

BOTTOM OF HOLE

Depth of bay water 8.67' @ start of boring - 0930 Hrs.

Depth scale (d): 5, 10, 15, 20, 25, 30, 35

DH-21
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.

N
E
COMPLETED: October 13, 1998

DH-22

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Wet, dk. brownish gray, SILT w/ tr. sand & mica (ML)		WH/1.5'	
4.5	Wet, reddish brown, SILT w/ tr. sand & mica (ML)		WH/1.5'	
9.5	Moist, lt. gray & brownish yellow, lean CLAY w/ tr. sand (CL)	5	1-1-2 3-4-7	
14.5	Very moist, lt. gray & yellowish brown, sandy{fine} lean CLAY (CL)	10	3-3-5 4-5-4	
17.0	Very moist, gray, sandy lean CLAY (CL)	15	1-1-1	
19.5	Very moist, gray, sandy fat CLAY (CH)		WH-1-1	
22.0	Very moist, dk. gray, sandy{fine} fat CLAY (CH)	20	1-1-1	
24.5	Very moist, dk. grayish brown, sandy{fine} fat CLAY (CH)		1-1-1	
26.5	Very moist, gray & brown, sandy{medium-fine} fat CLAY (CH)	25	2-5-6	
	BOTTOM OF HOLE			
	Depth of bay water 3.42' @ start of boring - 1651 Hrs.	30		
		35		

DH-22
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill | Auger | SPT | RB | Cored

GEO-2 SMI02.GPJ 7/13/00 13:35

STA.	ENVIRONMENTAL RESTORATION	N	DH-23
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:		COMPLETED:	October 13, 1998

DEPTH(ft)	(c)	(d)	Depth	(a)	(b)
2.0	Moist, gray, sandy{fine} SILT w/ tr. mica (ML)			WR-1/1.0'	
4.5	Very moist, gray & yellowish brown, lean CLAY w/ tr. fine sand & mica (CL) w/ tr. organics			WR/1.0'-WH	
9.5	Very moist, gray & yellowish brown, fat CLAY w/ tr. sand (CH)		5	1-1-2 2-3-4	
12.0	Very moist, gray & yellowish brown, lean CLAY w/ sand (CL)		10	4-5-8	
14.5	Wet, gray & yellowish brown, sandy{fine} silty CLAY (CL)			2-2-1	
15.7	Wet, yellowish brown, poorly graded SAND w/ silt (SP-SM)		15		
17.0	Wet, dk. gray, sandy{fine} lean CLAY (CL)			2-1-7	
24.5	Very moist, gray, fat CLAY w/ fine sand (CH) w/ tr. fine rounded gravel 22.5'-24.0'		20	WR-1-1 1-1-1 1-1-1	
26.5	Moist, gray, clayey fine SAND (SC)		25	1-1-1	
	BOTTOM OF HOLE		30		
	Depth of bay water 3.08' @ start of boring - 1438 Hrs.		35		

DH-23
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill | Auger | SPT | RB | Cored

STA.	ENVIRONMENTAL RESTORATION	N	DH-24
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:		COMPLETED:	October 16, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Wet, lt. yellowish brown, poorly graded fine SAND (SP)		2-4-1	
4.5	Very moist, lt. olive gray, SILT w/ fine sand & tr. mica (ML)		1-2-2	
7.0	Wet, gray, sandy{fine} SILT w/ fine sand & tr. mica (ML)		2-3-6	
9.5	Wet, lt. yellowish brown, poorly graded fine SAND w/ silt & tr. mica (SP-SM)		6-5-5	
12.0	Wet, gray, silty fine SAND (SM)		2-4-6	
14.5	Wet, gray, SILT w/ tr. fine sand & mica (ML)		1-1-1	
19.5	Very moist, gray, lean CLAY w/ medium-fine sand (CL)		1-1-1 1/.75'-1/.75'	
22.0	Very moist, greenish gray, sandy{medium-fine} lean CLAY w/ tr. mica (CL)		1-1-1	
24.5	Wet, greenish gray, sandy lean CLAY (CL)		1-1-1	
26.5	Wet, gray, clayey medium-fine SAND (SC)		1/1.0'-1	

Depth scale: 5, 10, 15, 20, 25, 30, 35

BOTTOM OF HOLE

Depth of bay water 2.42' @ start of boring - 1600 Hrs.

DH-24
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill | Auger | SPT | RB | Cored

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.

N
E
COMPLETED: October 16, 1998

DH-25

DEPTH(ft)	(c)	(d)	(a)	(b)
4.5	Moist, brownish yellow to lt. gray, lean CLAY w/ sand & tr. mica (CL)		1-1-1 1-2-3	
7.0	Very moist, lt. brownish gray, sandy{fine} SILT w/ tr. mica (ML)		3-3-5	
9.5	Wet, gray, sandy{fine} SILT w/ tr. mica (ML)		3-1-6	
17.0	Wet, gray, poorly graded medium-fine SAND w/ silt & tr. mica (SP-SM)		5-6-12 3-7-12 5-7-13	
26.5	Very moist, gray, clayey medium-fine SAND (SC)		1-1/1.0' 1-1/1.0' 1-1-2 1-1-1	

BOTTOM OF HOLE

Depth of bay water 3.25' @ start of boring - 1424 Hrs.

5 10 15 20 25 30 35

DH-25
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:36

STA.	ENVIRONMENTAL RESTORATION	N	**DH-26**
OFFSET:	SMITH ISLAND, MD.	E	**1 of 1**
TOP ELEV:		COMPLETED:	October 16, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Wet, gray, fat CLAY w/ fine sand & tr. roots (CH)		WH/1.5'	
4.5	Moist, gray & yellowish brown, sandy lean CLAY w/ tr. mica (CL)		2-4-10	
12.0	Moist, yellowish brown, silty fine SAND w/ tr. mica (SM)		2-2-5; 3-4-4; 3-4-5	
14.5	Moist, yellowish brown, poorly graded SAND w/ silt & tr. mica (SP-SM)		1-2-7	
17.0	Moist, brown, poorly graded SAND w/ silt & tr. mica (SP-SM)		5-4-3	
18.2	Wet, yellowish brown, silty medium-fine SAND w/ tr. mica (SM)		4-3-1	
19.5	Very moist, gray & yellowish brown, clayey fine SAND (SC)			
22.0	Very moist, gray, clayey fine SAND (SC)		1/.75'-1/.75'	
26.5	Very moist, gray, clayey medium-fine SAND (SC) w/ shell fragments 22.5'-24.0'		1-1-4; 3-1-1	

Depth scale: 5, 10, 15, 20, 25, 30, 35

BOTTOM OF HOLE

Depth of bay water 2.33' @ start of boring - 1242 Hrs.

DH-26
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill | Auger | SPT | RB | Cored

GEO-2 SMI02.GPJ 7/13/00 13:36

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.

N
E
COMPLETED: October 16, 1998

DH-27

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Wet, gray, sandy{fine} SILT w/ tr. mica (ML)		WR-WH/1.0'	
4.5	Moist, gray, lean CLAY w/ sand & tr. mica (CL)		2-5-8	
9.5	Moist, gray & lt. grayish brown, sandy{fine) SILT w/ tr. mica (ML)		3-5-6 3-3-4	
12.0	Moist, yellowish brown, silty medium-fine SAND w/ tr. mica (SM)		6-5-8	
14.5	Very moist, gray & yellowish brown, silty fine SAND w/ tr. mica (SM)		2-4-8	
19.5	Very moist, gray, fat CLAY w/ tr. sand & mica (CH)		1-1-1 1-1-1	
24.5	Very moist, gray & very dk. grayish brown, clayey medium-fine SAND w/ tr. mica (SC) w/ shell fragments 22.5'-24.0'		1-1/1.0' 2-2-2	
26.5	Very moist, grayish brown, silty medium-fine SAND w/ tr. mica (SM)		2-6-3	

BOTTOM OF HOLE

Depth of bay water 4.75' @ start of boring - 1026 Hrs.

DH-27
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

GEO-2 SMI02.GPJ 7/13/00 13:37

STA.
OFFSET:
TOP ELEV:

ENVIRONMENTAL RESTORATION
SMITH ISLAND, MD.

N
E
COMPLETED: October 14, 1998

DH-29

DEPTH(ft)	(c)	(d)		(a)	(b)
0.9	Wet, dk. grayish brown, lean CLAY w/ tr. fine sand (CL)			WR/1.0'-1	
4.5	Very moist, gray & yellowish brown, lean CLAY w/ tr. fine sand (CL)			1-4-5	
7.0	Very moist, yellowish brown, sandy{fine} SILT w/ tr. mica (ML)		5	4-6-6	
9.5	Moist, gray & dk. yellowish brown, sandy{fine} SILT w/ tr. mica (ML)			3-3-3	
12.0	Moist, dk. gray, sandy{fine} lean CLAY w/ tr. mica (CL)		10	1-1-1	
17.0	Very moist, dk. gray & dk. brownish gray, sandy{fine} lean CLAY w/ tr. mica (CL)		15	1-1/1.0'	
				1-1/1.0'	
18.1	Very moist, dk. gray & dk. brownish gray, sandy{fine} lean CLAY w/ tr. mica & gravel (CL)			4-24-36	
19.5	Moist, brown, poorly graded coarse-fine SAND w/ silt & tr. gravel (SP-SM)		20		
22.0	Moist, brown, poorly graded medium-fine SAND w/ silt & tr. gravel (SP-SM)			11-7-15	
23.4	Very moist, dk. brownish gray, silty coarse-fine SAND (SM)			1-1-2	
24.5	Moist, dk. grayish brown, sandy lean CLAY w/ tr. mica (CL)				
25.6	Moist, gray & grayish brown, silty medium-fine SAND w/ tr. gravel (SM)		25	9-19-28	
25.9	Moist, gray & grayish brown, silty coarse-fine SAND w/ tr. gravel (SM)				
26.5	Moist, lt. brownish gray, silty medium-fine SAND w/ tr. gravel (SM)				
	BOTTOM OF HOLE		30		
	Depth of bay water 5.83' @ start of boring - 1119 Hrs.		35		

DH-29
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

STA.	ENVIRONMENTAL RESTORATION	N	DH-30
OFFSET:	SMITH ISLAND, MD.	E	1 of 1
TOP ELEV:		COMPLETED:	October 14, 1998

DEPTH(ft)	(c)	(d)	(a)	(b)
2.0	Moist, yellowish brown, SILT w/ fine sand & tr. mica (ML)		1-4-4	
4.5	Moist, gray & yellowish brown, SILT w/ fine sand & tr. mica (ML)		5-6-6	
7.0	Moist, gray, SILT w/ fine sand & tr. mica (ML)	5	3-3-7	
9.5	Moist, gray, clayey SAND w/ tr. mica (SC)		1-1-1	
12.0	Very moist, gray, clayey medium-fine SAND w/ tr. mica (SC)	10	WR-WH/1.0'	
13.5	Very moist, gray & yellowish brown, clayey medium-fine SAND w/ tr. mica (SC)		1-4-7	
14.5	Very moist, gray, silty medium-fine SAND w/ tr. mica (SM)			
17.0	Very moist, gray & dk. grayish brown, silty medium-fine SAND w/ tr. mica (SM)	15	8-11-11	
19.5	Very moist, gray, poorly graded medium-fine SAND w/ tr. mica (SP)		8-24-29	
22.0	Very moist, gray & dk. grayish brown, poorly graded medium-fine SAND w/ tr. mica (SP) w/ tr. fine gravel	20	4-4-4	
24.5	Very moist, gray & dk. grayish brown, clayey medium-fine SAND (SC)		2-4-5	
26.5	Moist, gray & dk. grayish brown, fat CLAY w/ tr. sand (CH)	25	2-2-2	

BOTTOM OF HOLE

Depth of bay water 7.58' @ start of boring - 1458 Hrs.

30

35

DH-30
GROUNDWATER DATA
WHILE DRILLING:
ON COMPLETION:
Hr. READING:

Fill Auger SPT RB Cored

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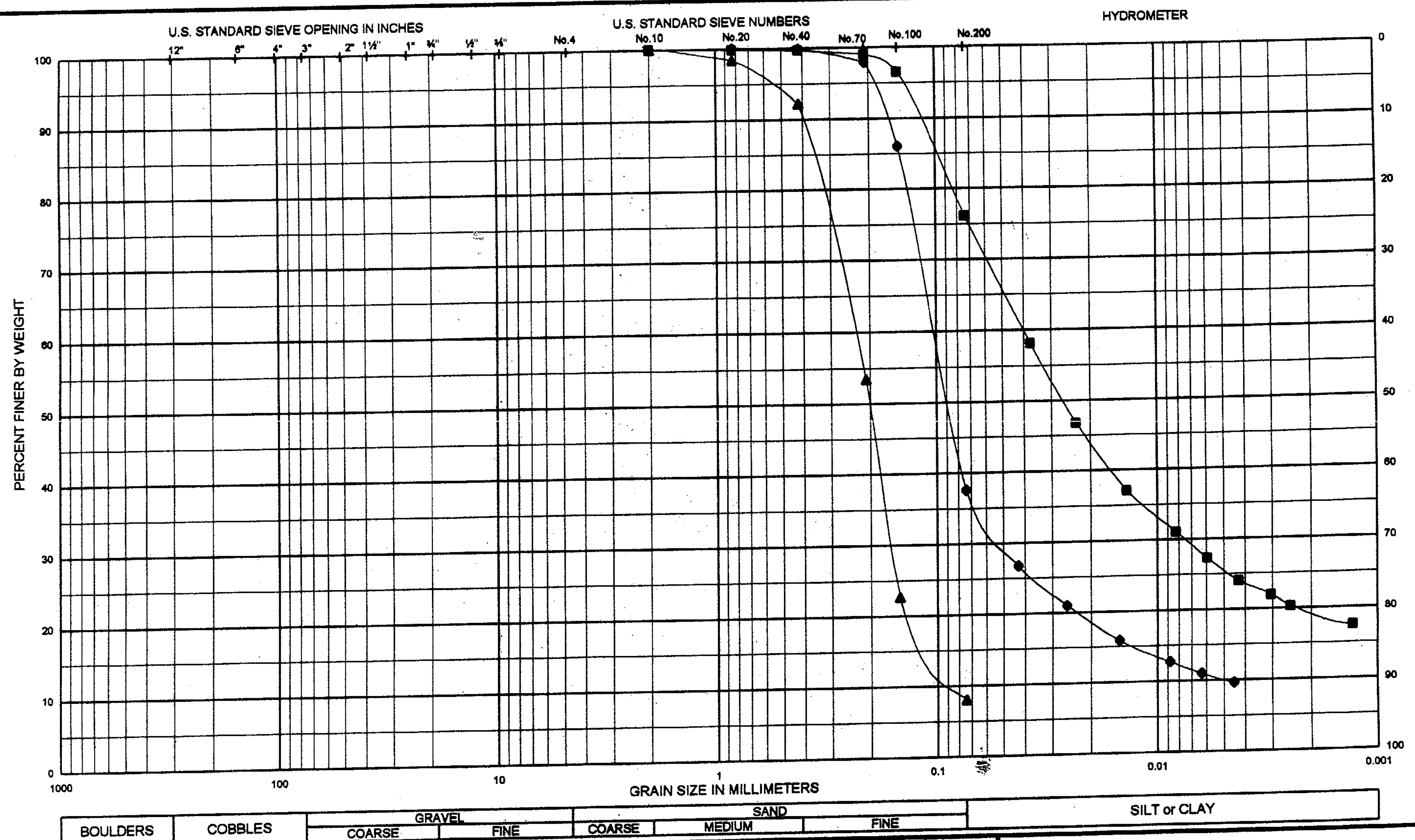


Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-2,3	0.4-4.0	Lean clay with sand (tr. mica) BC-1-1-1-4-4 (CL)	——	——	——	——
—◆—	Jar-5,6	7.5-11.0	Silty sand (tr. mica) BC-2-1-2-3-2 (SM)	——	——	——	——
—▲—	Jar-7,8,9	11.0-16.3	Poorly graded sand with silt (tr. mica) BC-3-3-6-8-3-3-2 (SP-SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

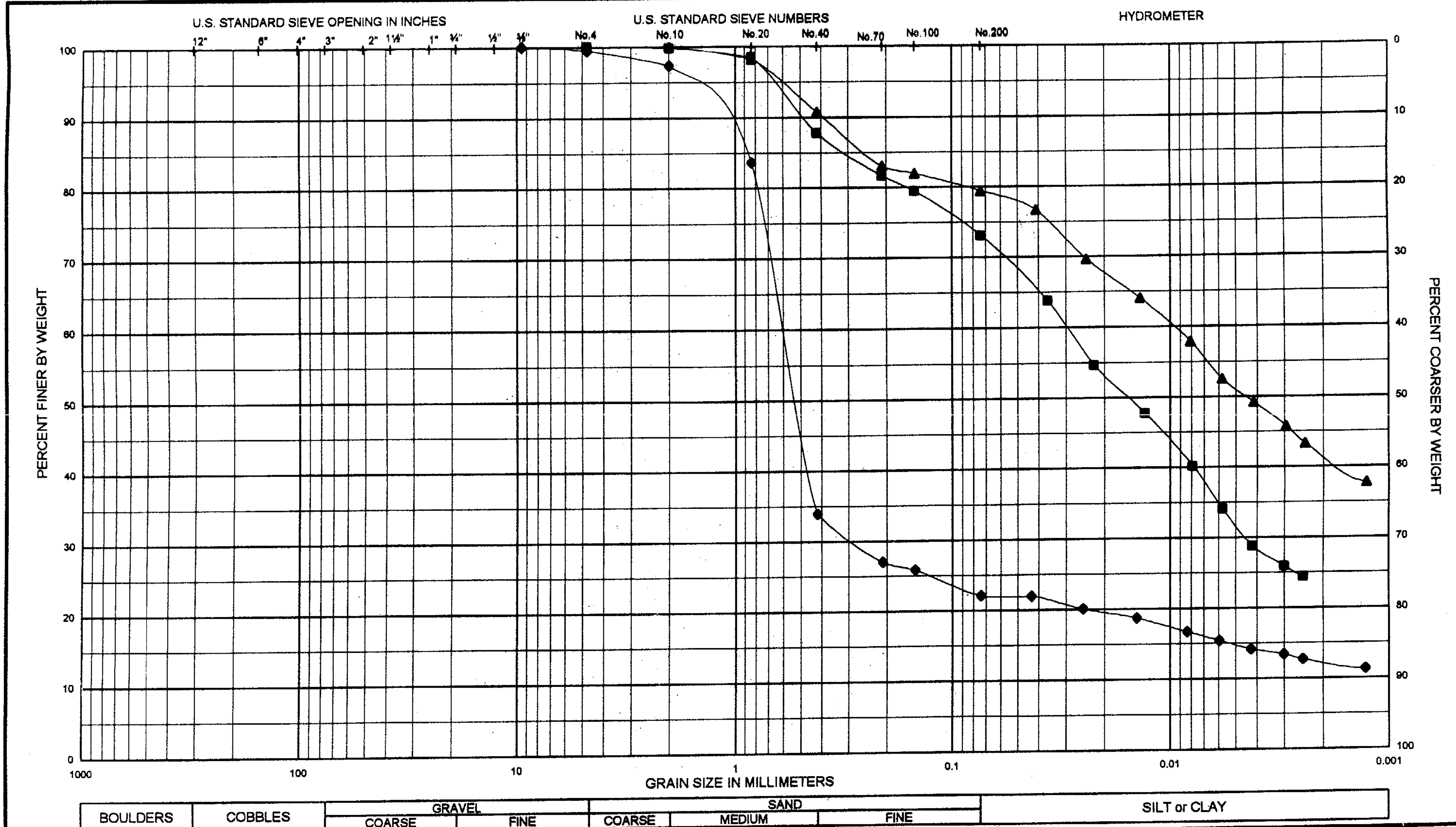
AREA: Somerset County, MD

Boring No.: DH-1 Sht. 1 of 2

DATE: Jan 1999

GRADATION CURVES

ENG FORM 2087



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-10,11	16.3-18.4	Lean clay with sand (tr. mica) BC-1-1	(CL)	——	47	21	26
—◆—	Jar-13	20.0-21.5	Clayey sand (tr. mica) BC-1-2-1	(SC)	——	——	——	——
—▲—	Jar-15	25.0-26.5	Fat clay with sand BC-2-3-2	(CH)	——	78	23	55

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

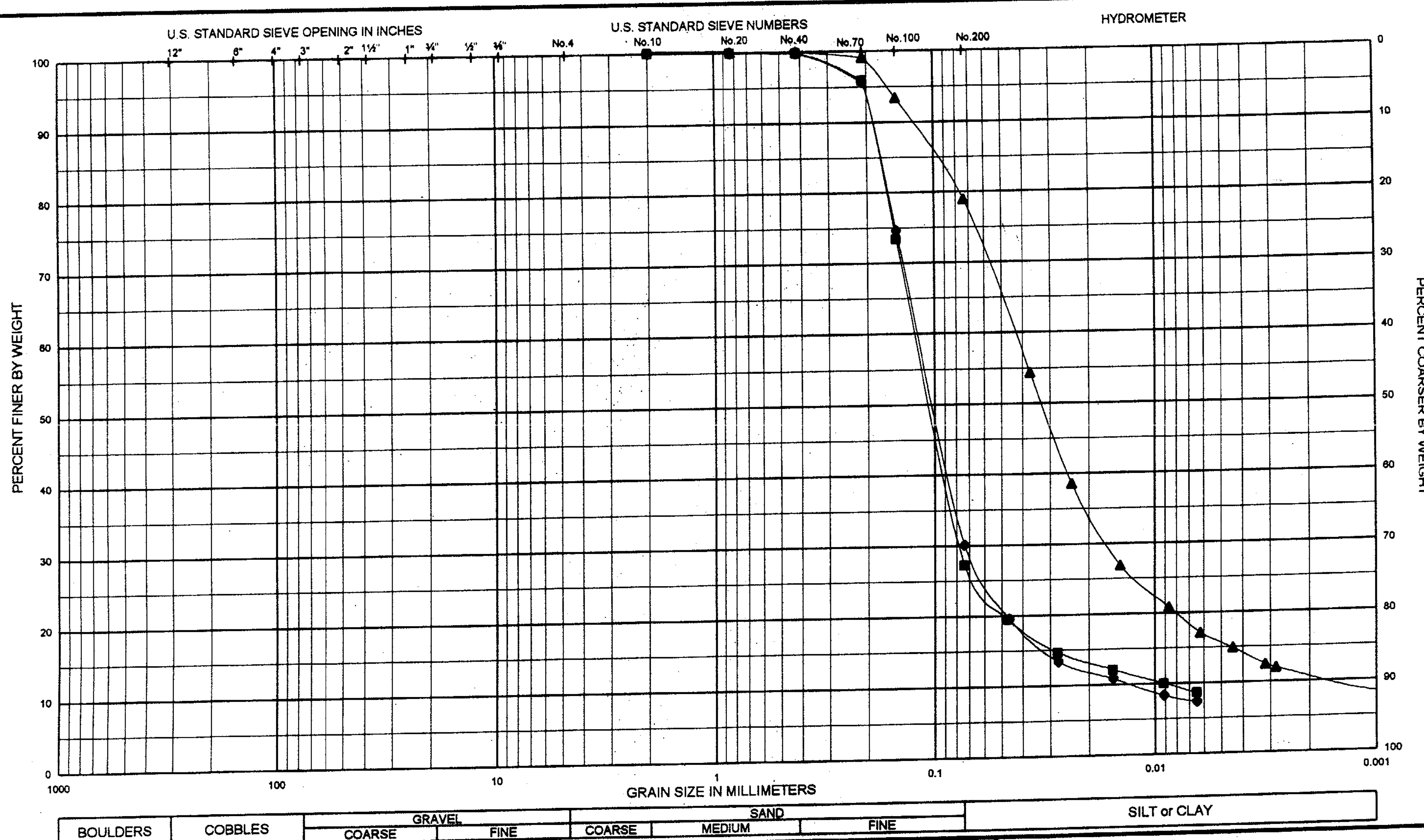
AREA: Somerset County, MD

Boring No.: DH-1 Sht. 2 of 2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1-4	0.0-9.0	Silty sand (tr. mica) BC-WOR-2-5-3-2-3-3-2-3-2-55 (SM)	——	——	——	——
—◆—	Jar-6,7	10.8-14.0	Silty sand (tr. mica) BC-2-4-2-4 (SM)	——	——	——	——
—▲—	Jar-8	15.0-15.7	Lean clay with sand BC-5 (CL)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

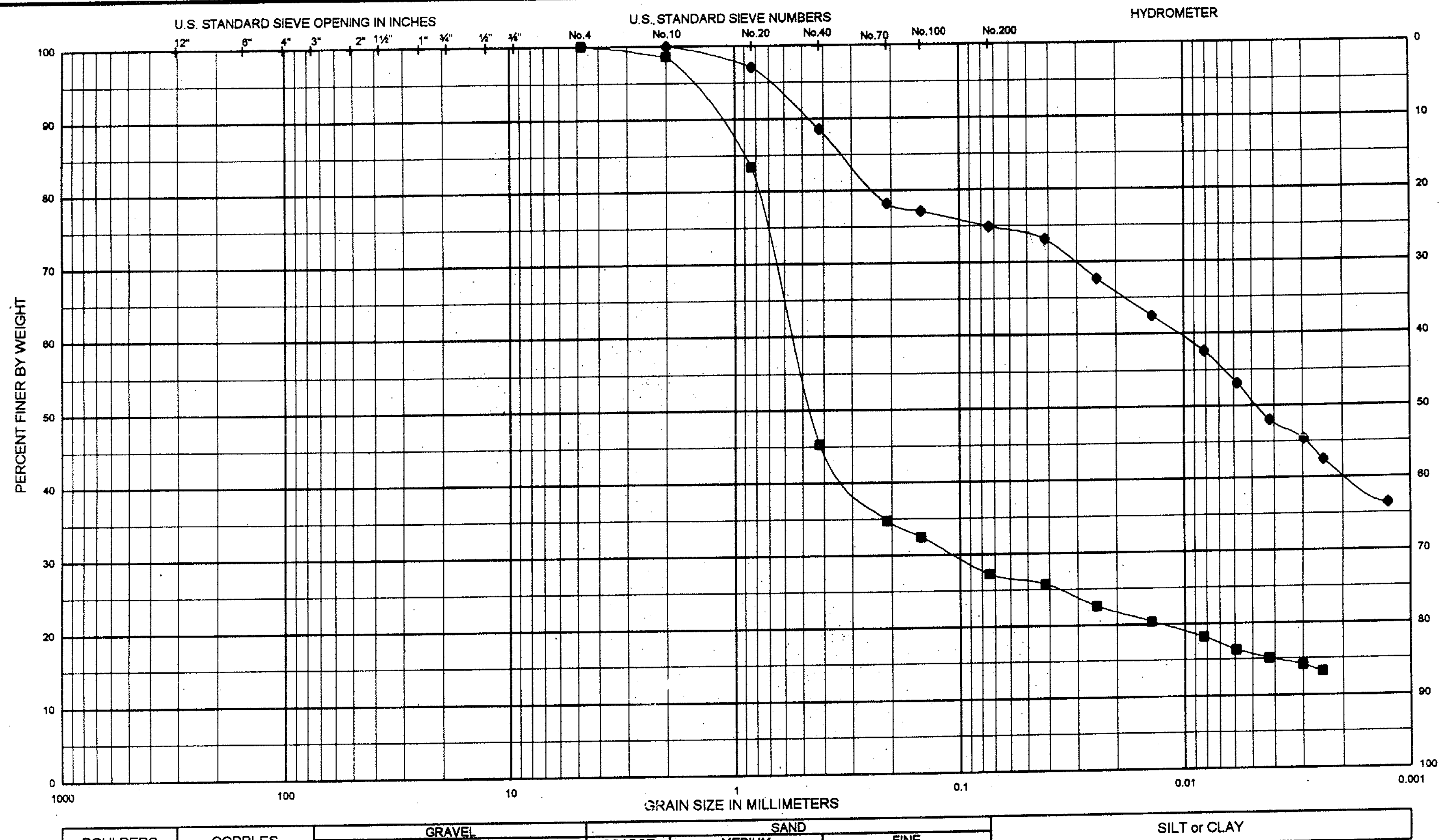
AREA: Somerset County, MD

Boring No.: DH-2 Sht. 1 of 2

DATE: Jan 1999

GRADATION CURVES

ENG FORM 2087



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-10,11	17.5-21.5	Clayey sand BC-wot/.75'-1/.75'-1-1-1 (SC)	—	—	—	—
—◆—	Jar-12,13	22.5-26.5	Fat clay with sand BC-1-1-2-5-6-9 (CH)	—	75	23	52

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

AREA: Somerset County, MD

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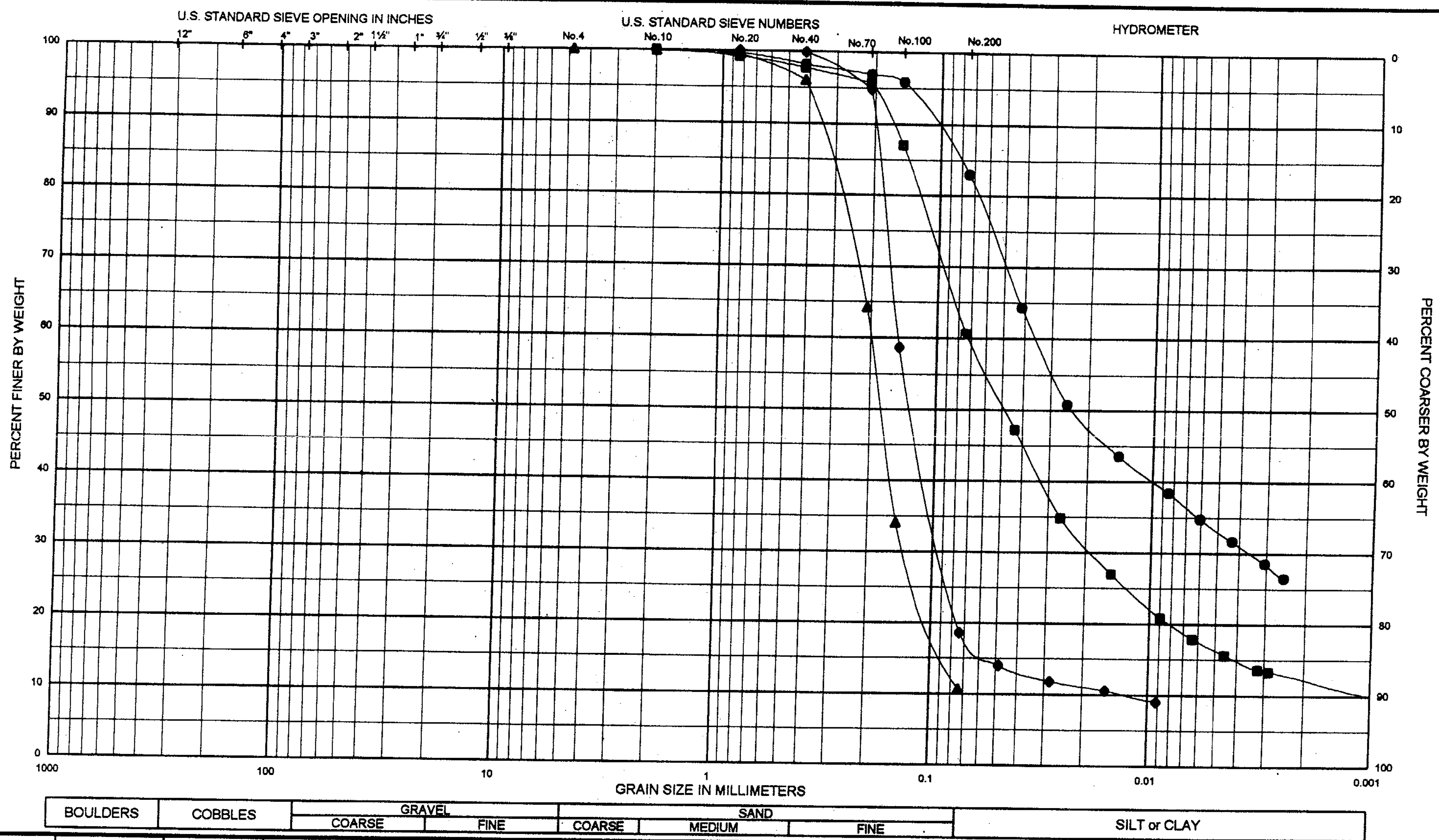
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-1-4	0.0-5.6	Sandy lean clay BC-woe/i'-1-2-2-4-3	(CL)	——	27	18	9
—◆—	Jar-5	5.6-6.5	Silty sand BC-6-7	(SM)	——	——	——	——
—▲—	Jar-6-9	7.5-15.9	Poorly graded sand with silt (tr. mica)	(SP-SM)	——	——	——	——
—●—	Jar-10	15.9-16.5	Lean clay with sand BC-1	(CL)	——	43	20	23

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

AREA: Somerset County, MD

Boring No.: DH-3 Sht. 1 of 2

DATE: Jan 1999

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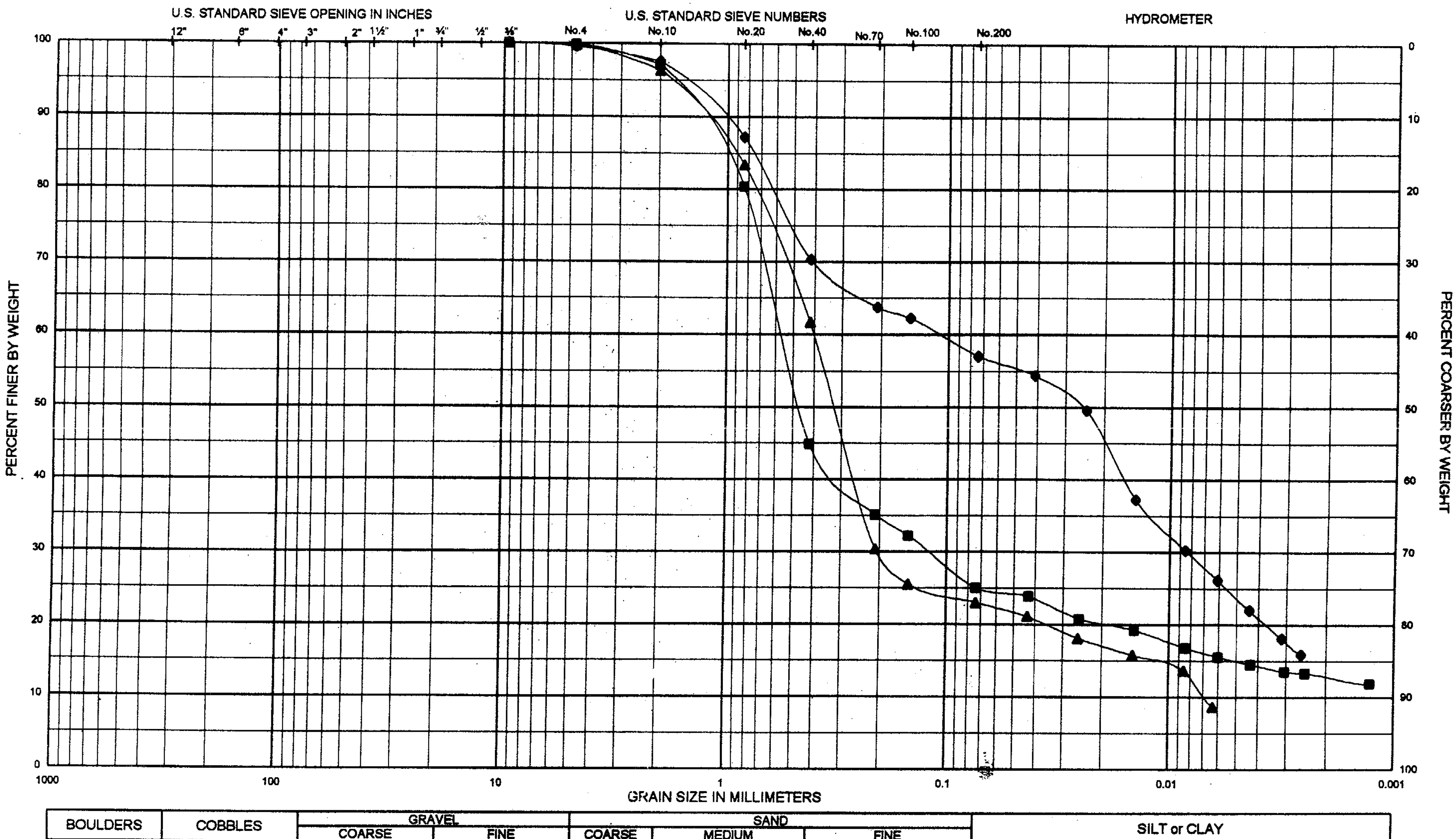
GRADATION CURVES

BC- 5-6-7-4-9-9-3-5-3-3-2



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-11	17.5-19.0	Clayey sand BC - 1/.75' - 1/.75'	(SC)	———	———	———	———
—◆—	Jar-12,13	20.0-24.0	Sandy fat clay BC - 3-1-1 3-2-2	(CH)	———	71	22	49
—▲—	Jar-14	25.0-26.5	Clayey sand BC - 2-3-3	(SC)	———	———	———	———

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

AREA: Somerset County, MD

Boring No.: DH-3 Sht. 2 of 2

DATE: Jan 1999

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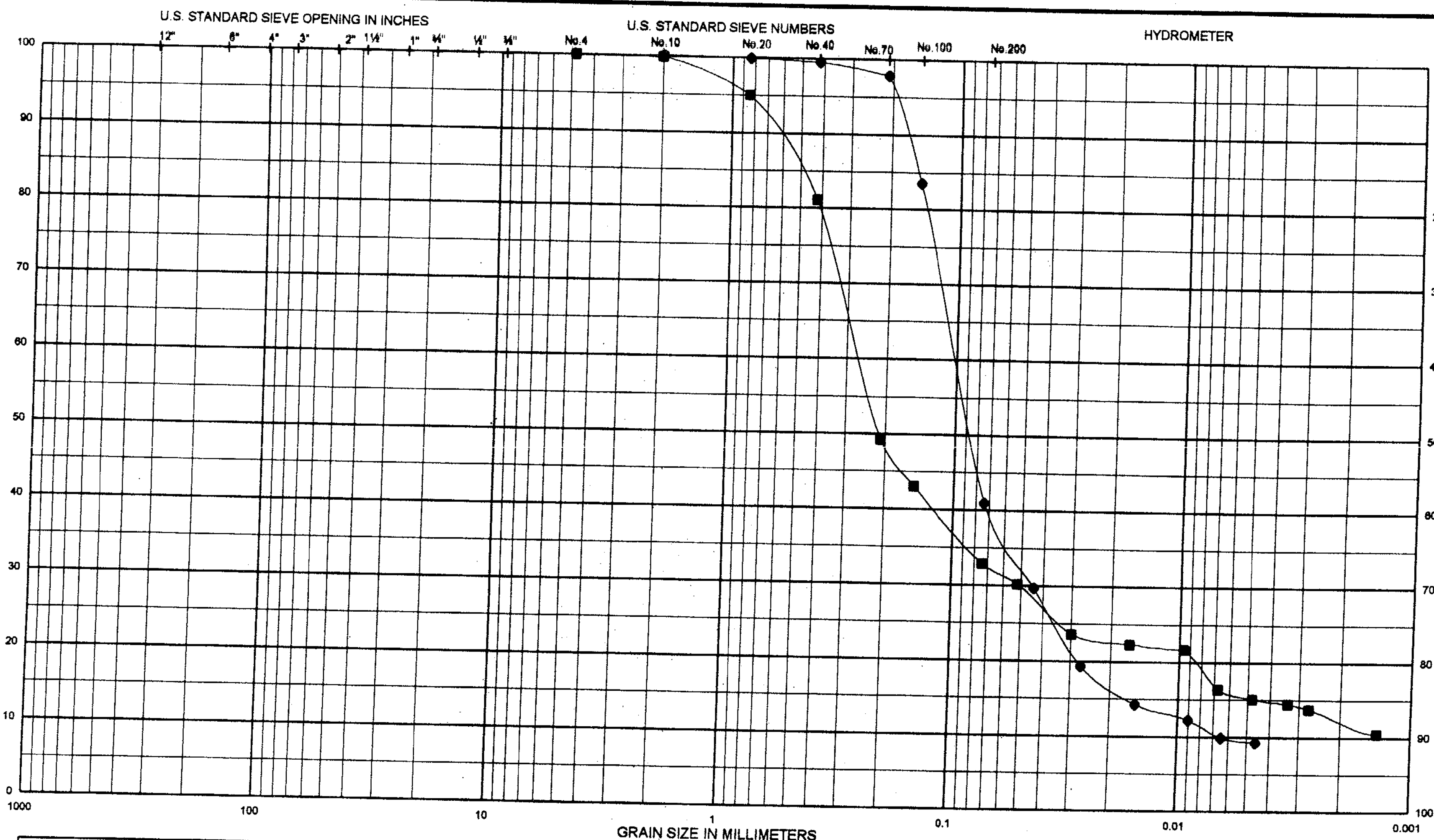
GRADATION CURVES



BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-0.5	Silty sand BC - WOR (SM)	——	——	——	——
—◆—	Jar-2,3	0.5-4.0	Silty sand BC- 1-1-WOH/1.5' (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

AREA: Somerset County, MD

Boring No.: DH-4

DATE: Jan 1999

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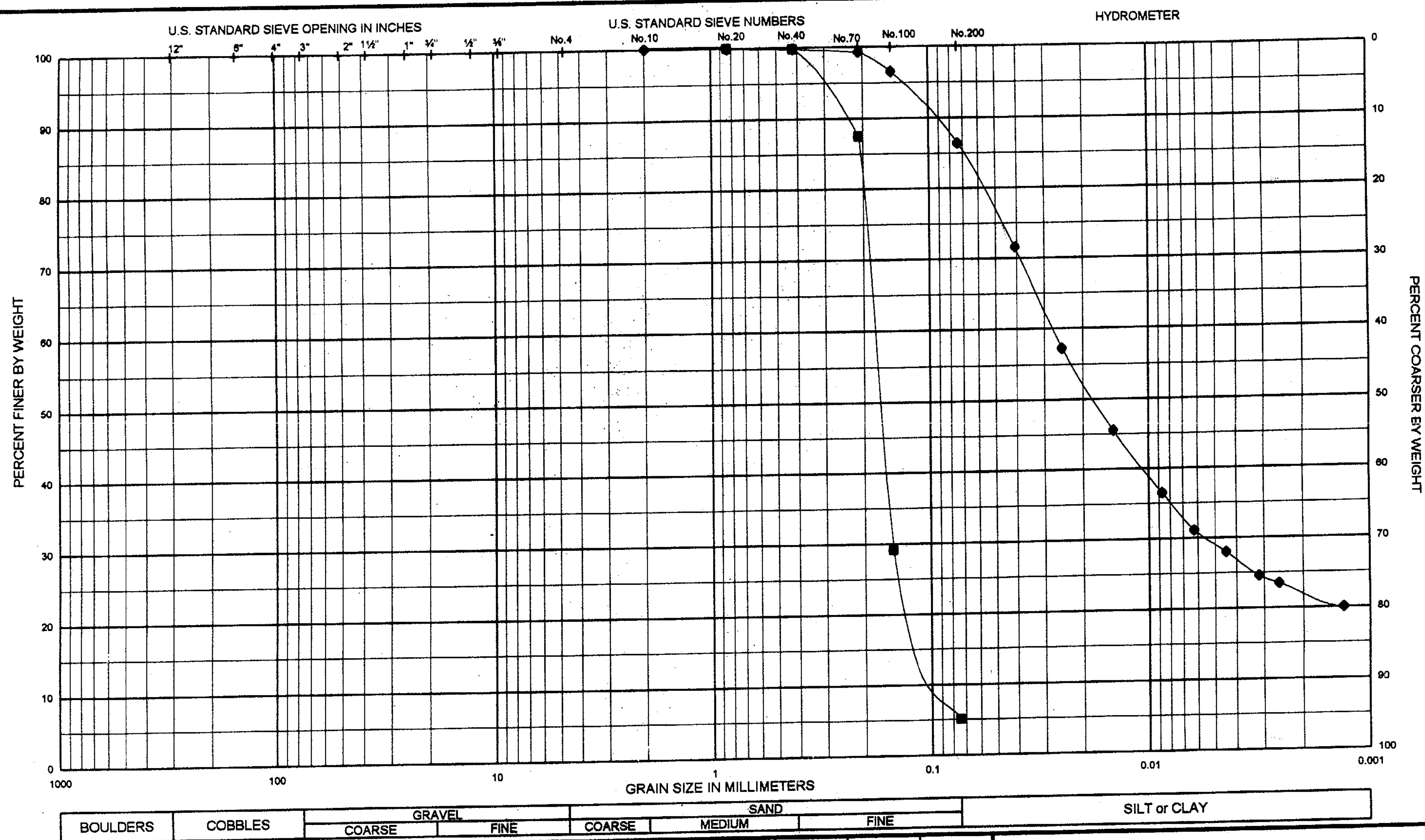
GRADATION CURVES

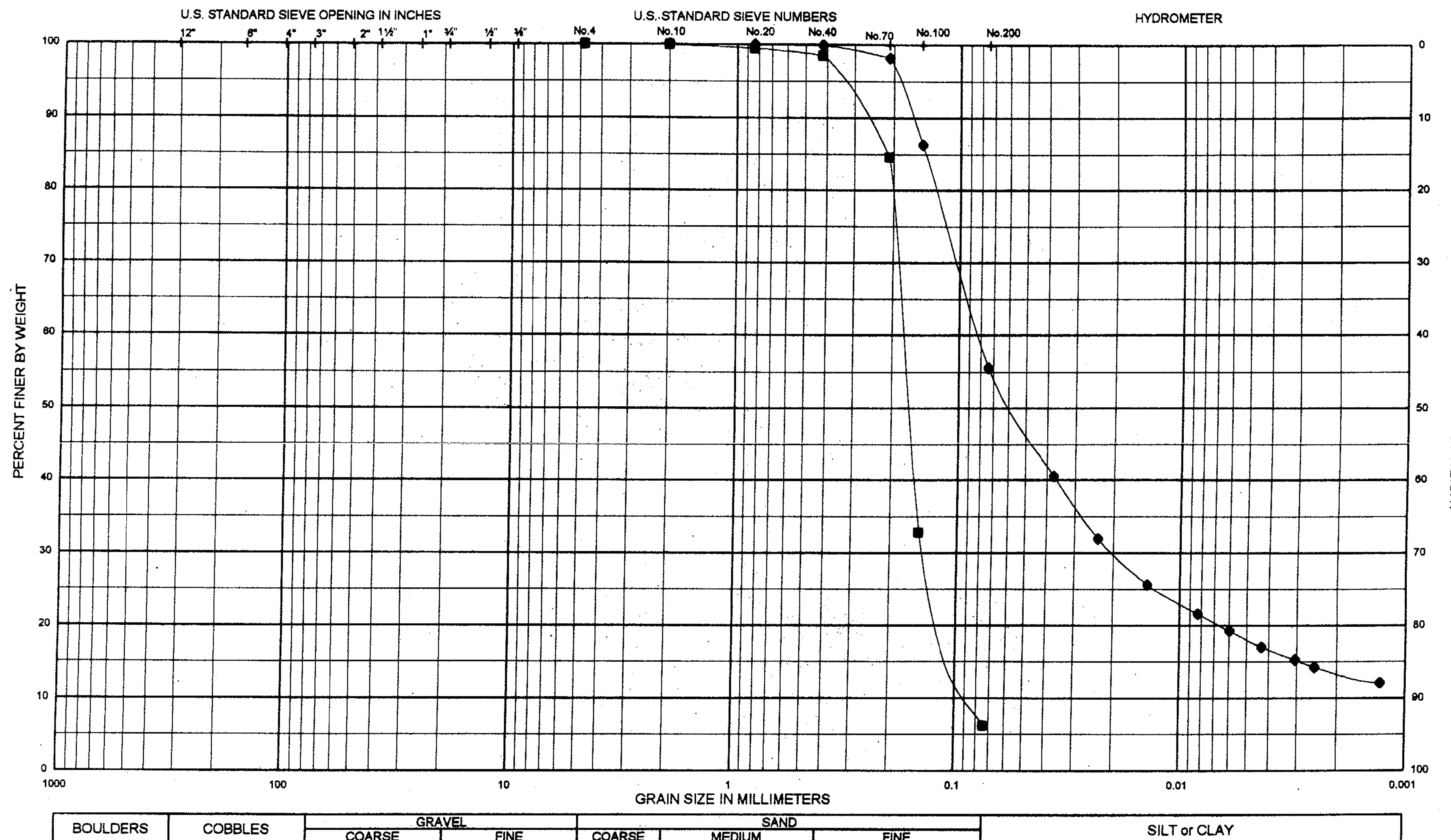


Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-3.4	Poorly graded sand with silt BC-1-3-4-2-2 (SP-SM)	——	——	——	——
—◆—	Jar-3	3.4-4.0	Lean clay (tr. sand) BC-1 (CL)	——	——	——	——

PROJECT:	Smith Island Environmental Restoration Sheep Pen Gut
AREA:	Somerset County, MD
Boring No.:	DH-5
DATE:	Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-1.5	Poorly graded sand with silt BC-WOR-3-2 (SP-SM)	——	——	——	——
—◆—	Jar-2,3	2.5-6.5	Sandy lean clay (tr. mica) BC-5-2-1-2-3-4 (CL)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

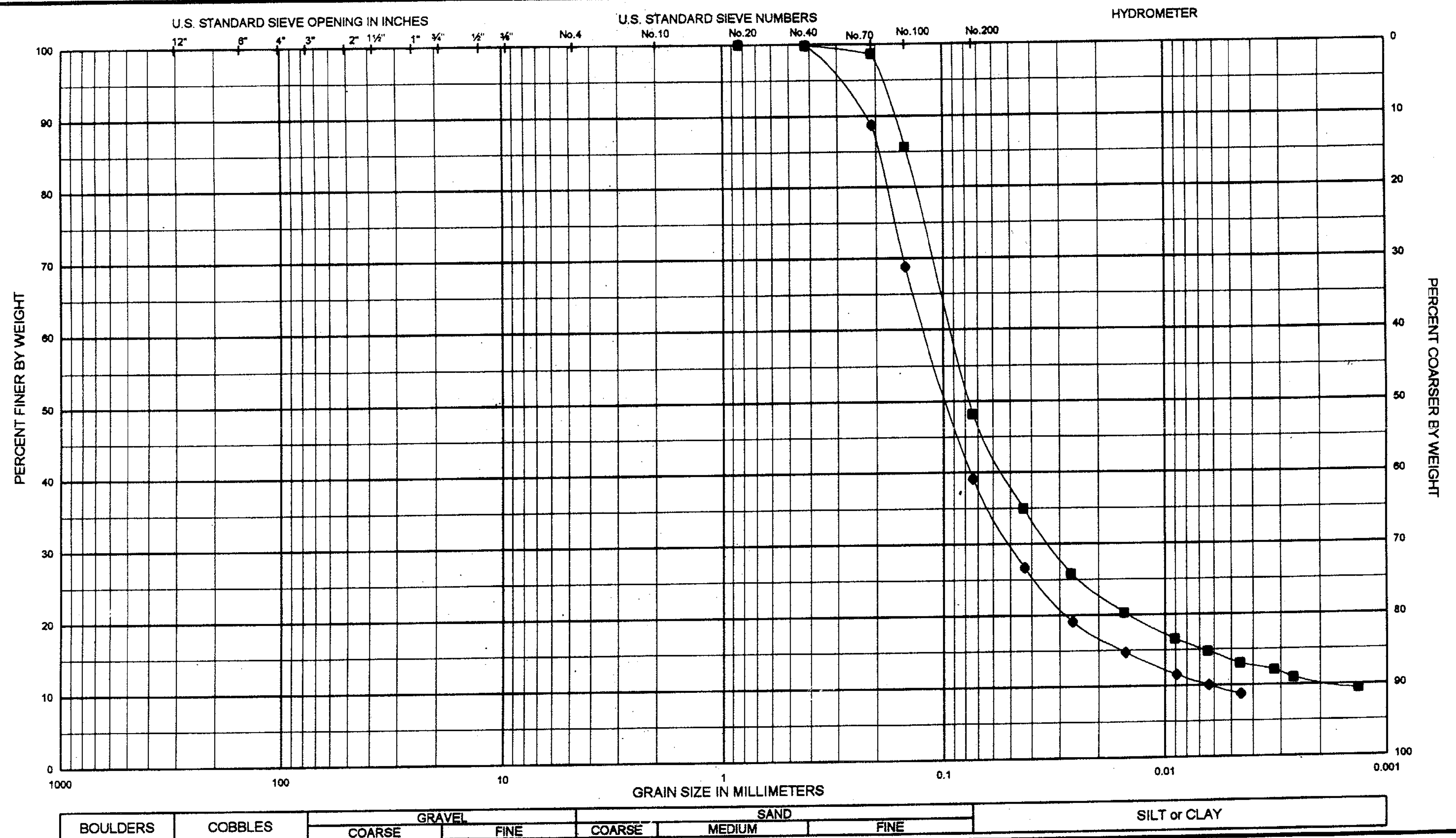
AREA: Somerset County, MD

Boring No.: DH-6

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES

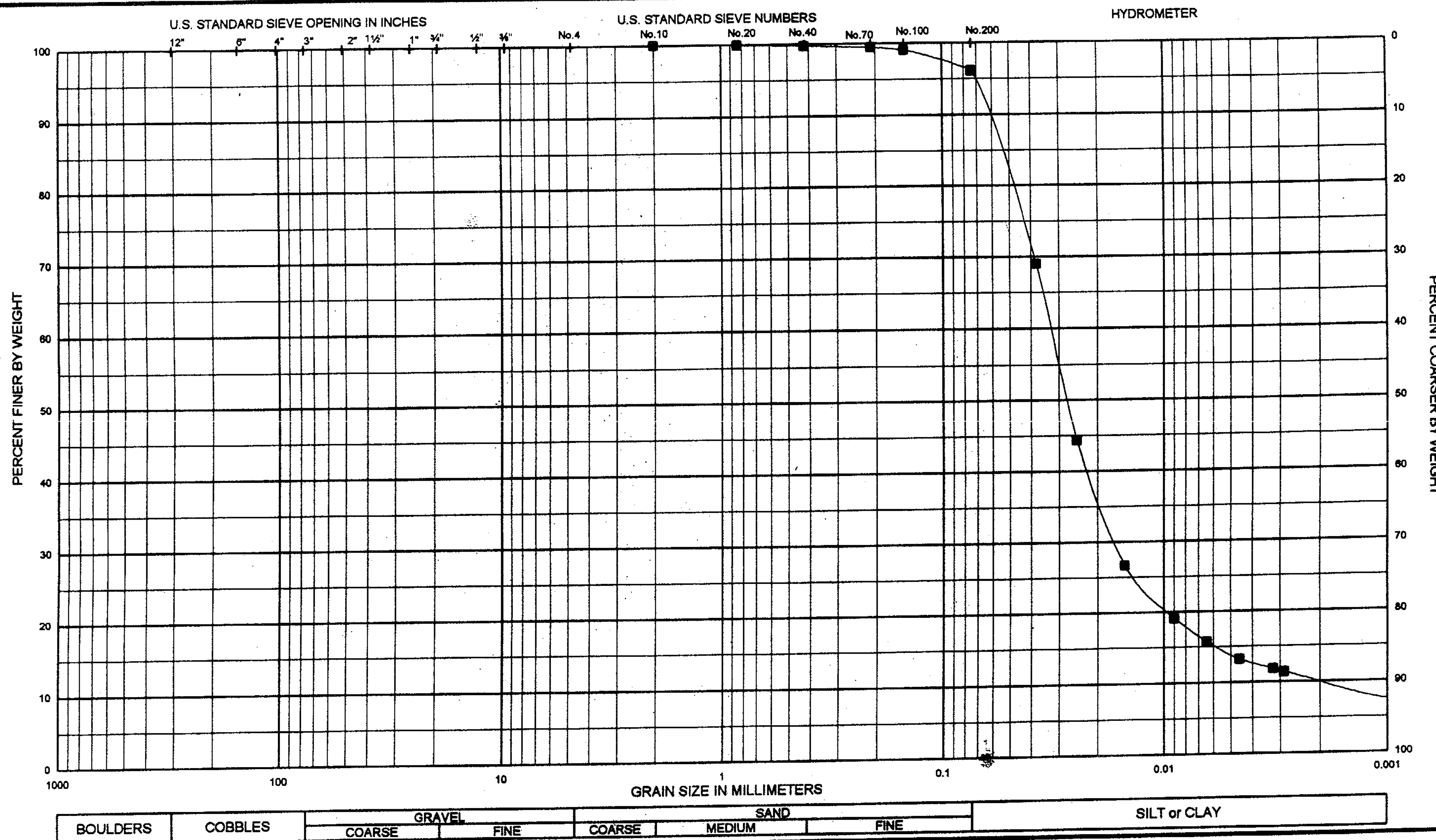


Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-2	2.5-4.0	Silty sand Bc-3-2-1 (SM)	——	——	——	——
—◆—	Jar-3	5.0-6.5	Silty sand Bc-1-5-6 (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut
AREA: Somerset County, MD
Boring No.: DH-7
DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-3	5.0-6.5	Silt (tr. sand) BC-3-3-2 (ML)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Sheep Pen Gut

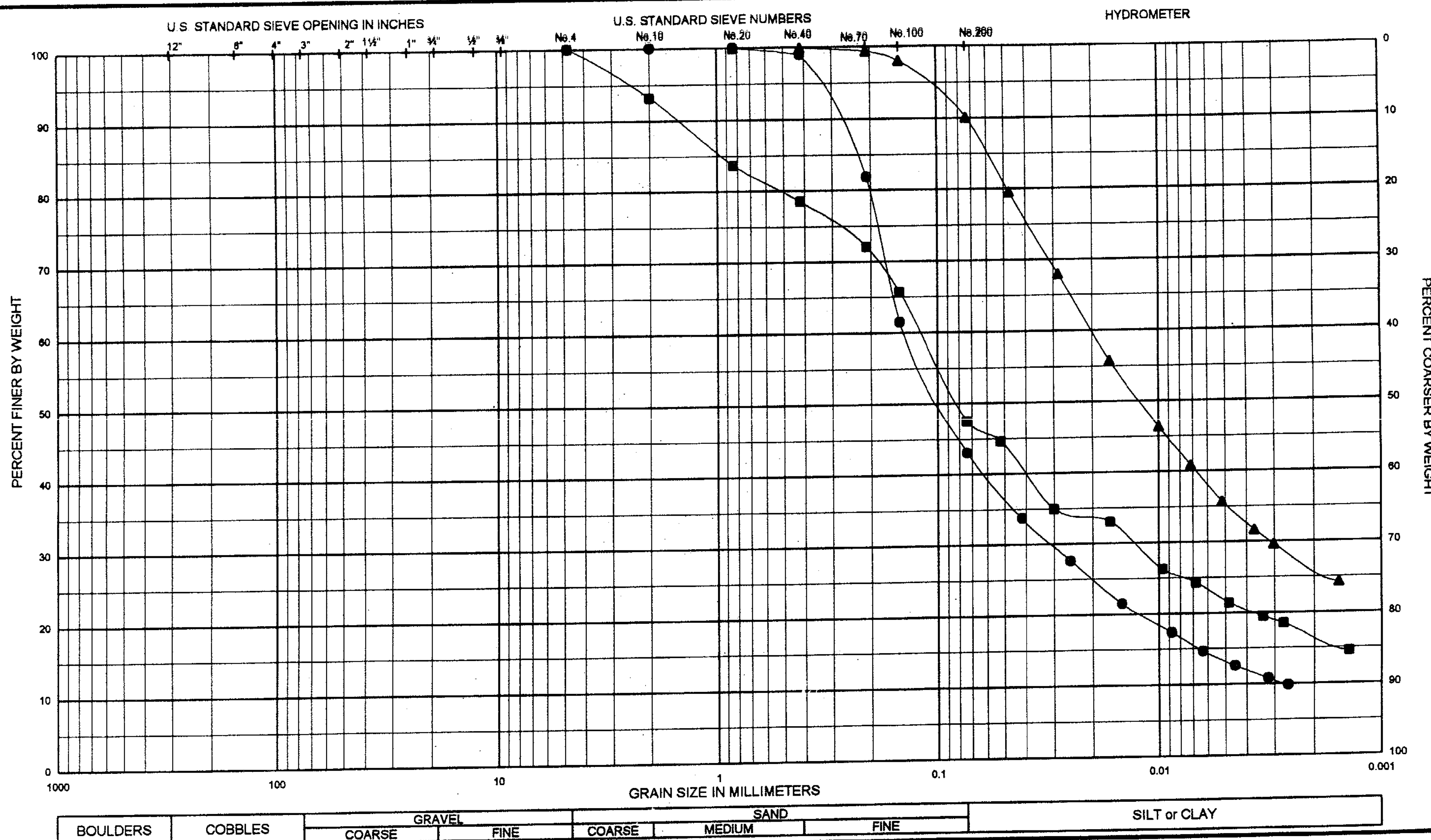
AREA: Somerset County, MD

Boring No.: DH-11

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-1*	0.0-0.4	Very organic silty sand BC-WOR	(SM)	——	——	——	——
	"	"	* L.O.I. = 50.2% - Very organic					
—▲—	Jar-2-4	0.4-6.5	Lean clay (tr. sand) BC-WOH-1-1-1-5-6-9	(CL)	——	31	17	14
—●—	Jar-6	8.0-8.3	Clayey sand (tr. mica) BC-10	(SC)	——	——	——	——

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AREA: Somerset County, MD

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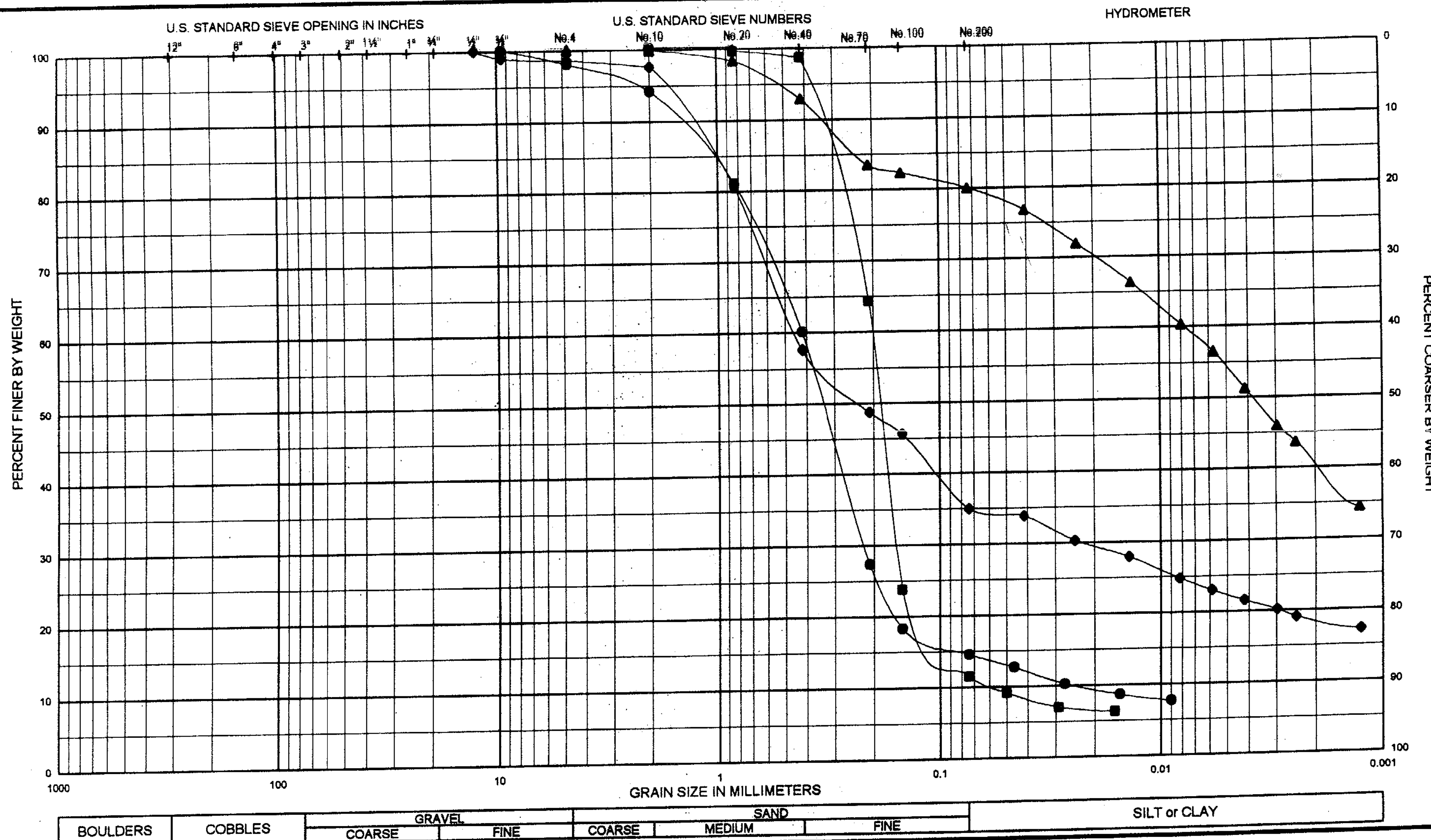
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification 6-5-6	Nat w%	LL	PL	PI
—■—	Jar-7-10	8.3-16.5	Poorly graded sand with silt BC-10-6-7-8-5-9-8' (SP-SM)	———	———	———	———
—◆—	Jar-11,12	17.5-21.5	Clayey sand (tr. gravel) BC-1-1/10' -2-2-1 (SC)	———	———	———	———
—▲—	Jar-13	22.5-24.0	Fat clay with sand BC-1-1-1 (CH)	———	75	23	52
—●—	Jar-14	25.0-26.5	Silty sand (tr. gravel) BC-3-4-13 (SM)	———	———	———	———

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Sheep Pen Gut

AREA: Somerset County, MD

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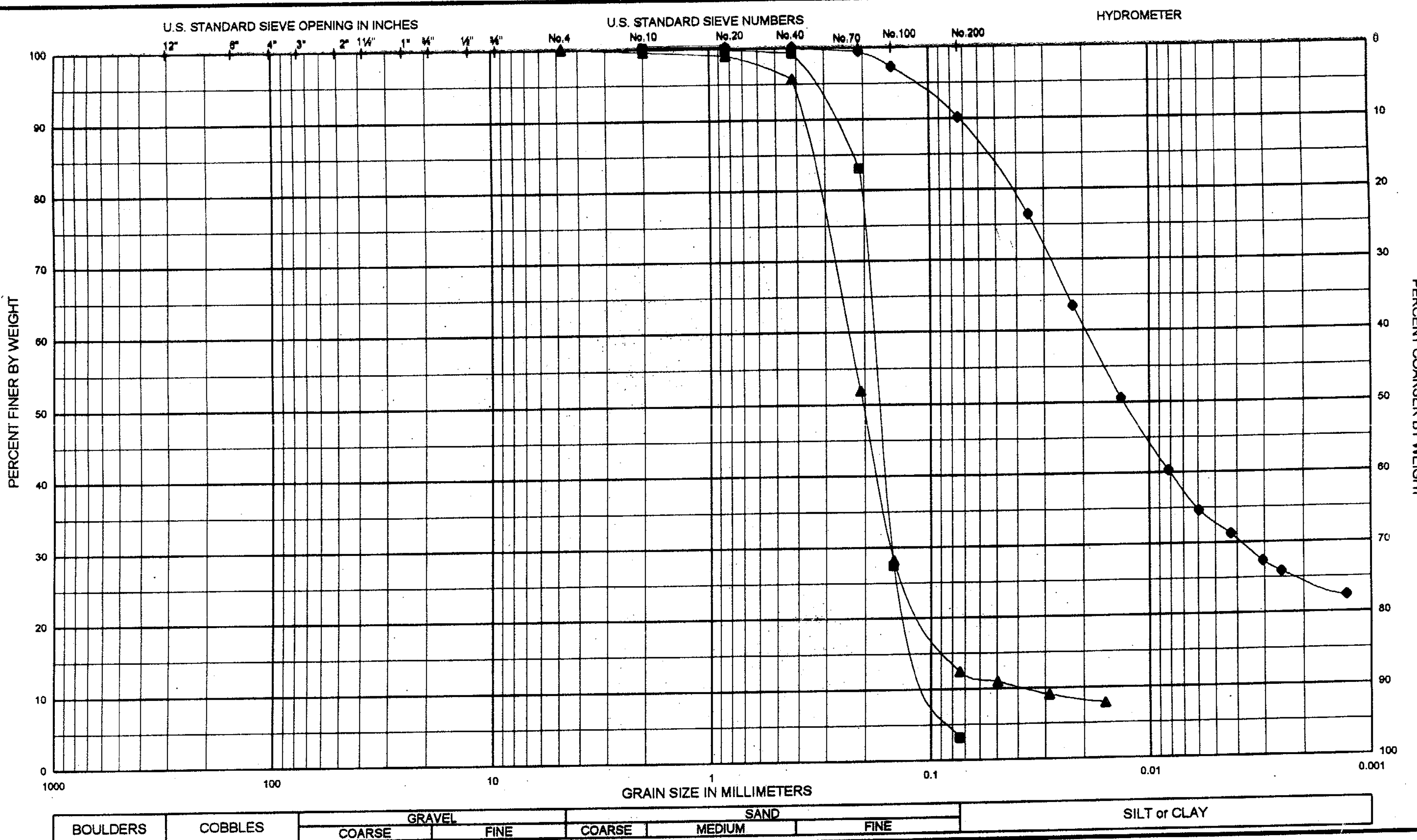

Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-1	0.0-0.3	Poorly graded sand (tr. mica) BC-WOR	(SP)	——	——	——	——
—◆—	Jar-2,3	0.3-4.0	Lean clay (tr. sand) BC-1-WOR-1-4	(CL)	——	33	18	15
—▲—	Jar-6,7	10.0-13.4	Silty sand BC-2-3-3-2-2	(SM)	——	——	——	——

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AREA: Somerset County, MD

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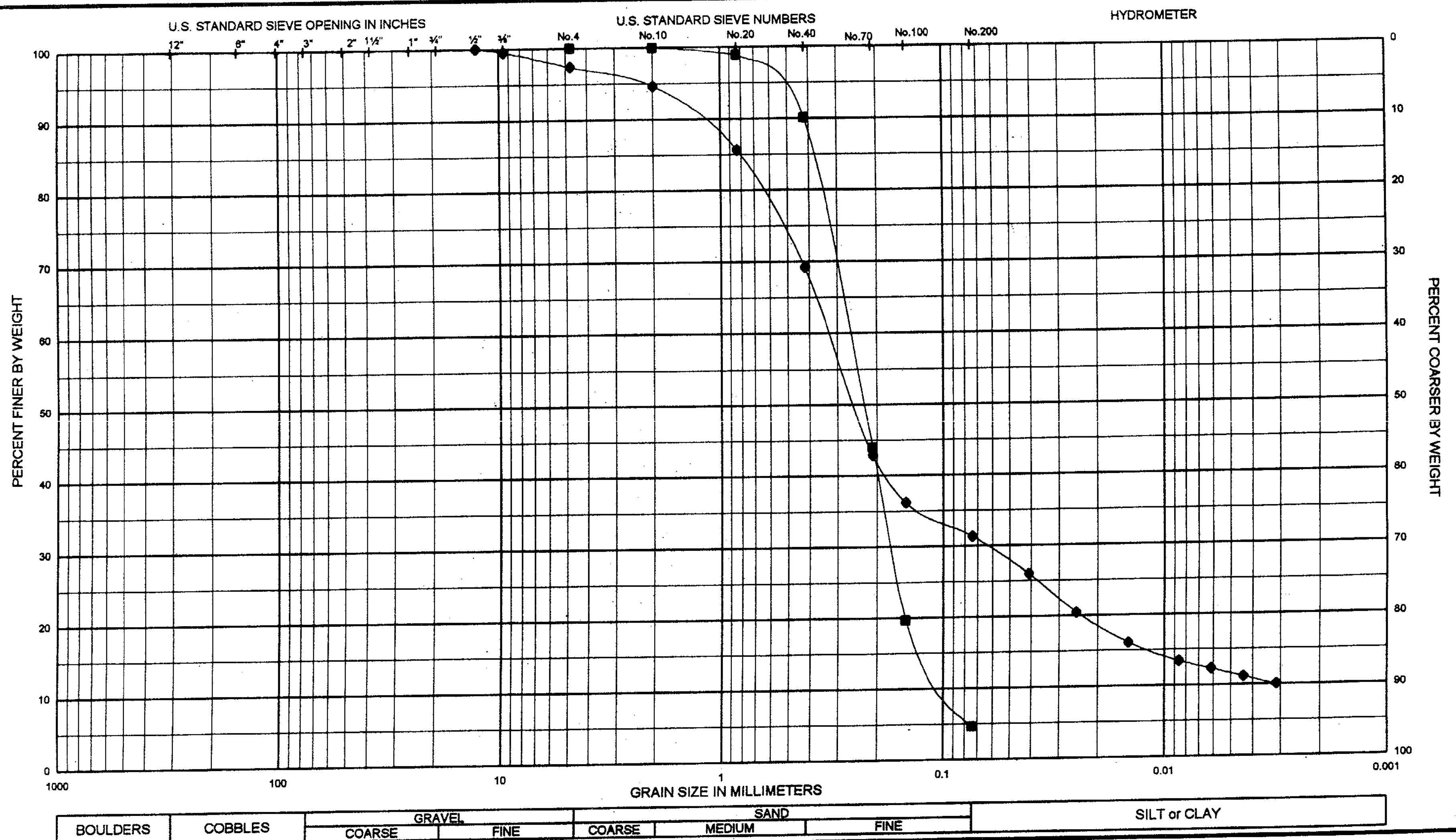
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-9	15.0-16.5	Poorly graded sand (tr. mica) BC-4-6-5	(SP)	——	——	——	——
—◆—	Jar-14	25.0-26.5	Clayey sand (tr. gravel) BC-2-5-11	(SC)	——	——	——	——

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AREA: Somerset County, MD

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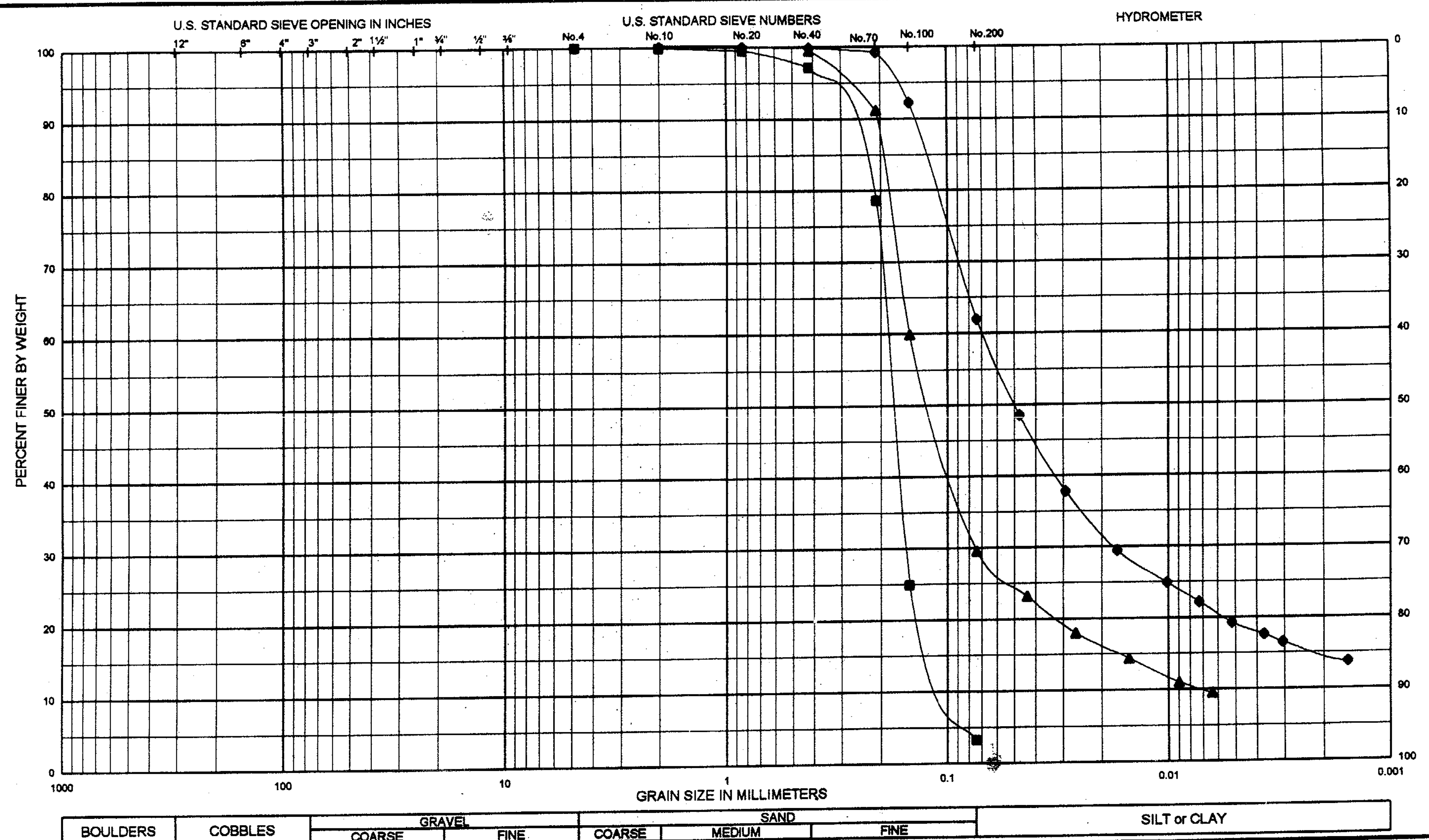
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
■	Jar-1	0.0-1.5	Poorly graded sand BC-3-3-2 (SP)	——	——	——	——
◆	Jar-2	2.5-4.0	Sandy silt BC-WOH-3-5 (ML)	——	——	——	——
▲	Jar-3,4	5.0-9.0	Silty sand (tr. mica) BC-4-7-9-5-4-7 (SM)	——	——	——	——

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AREA: Somerset County, MD

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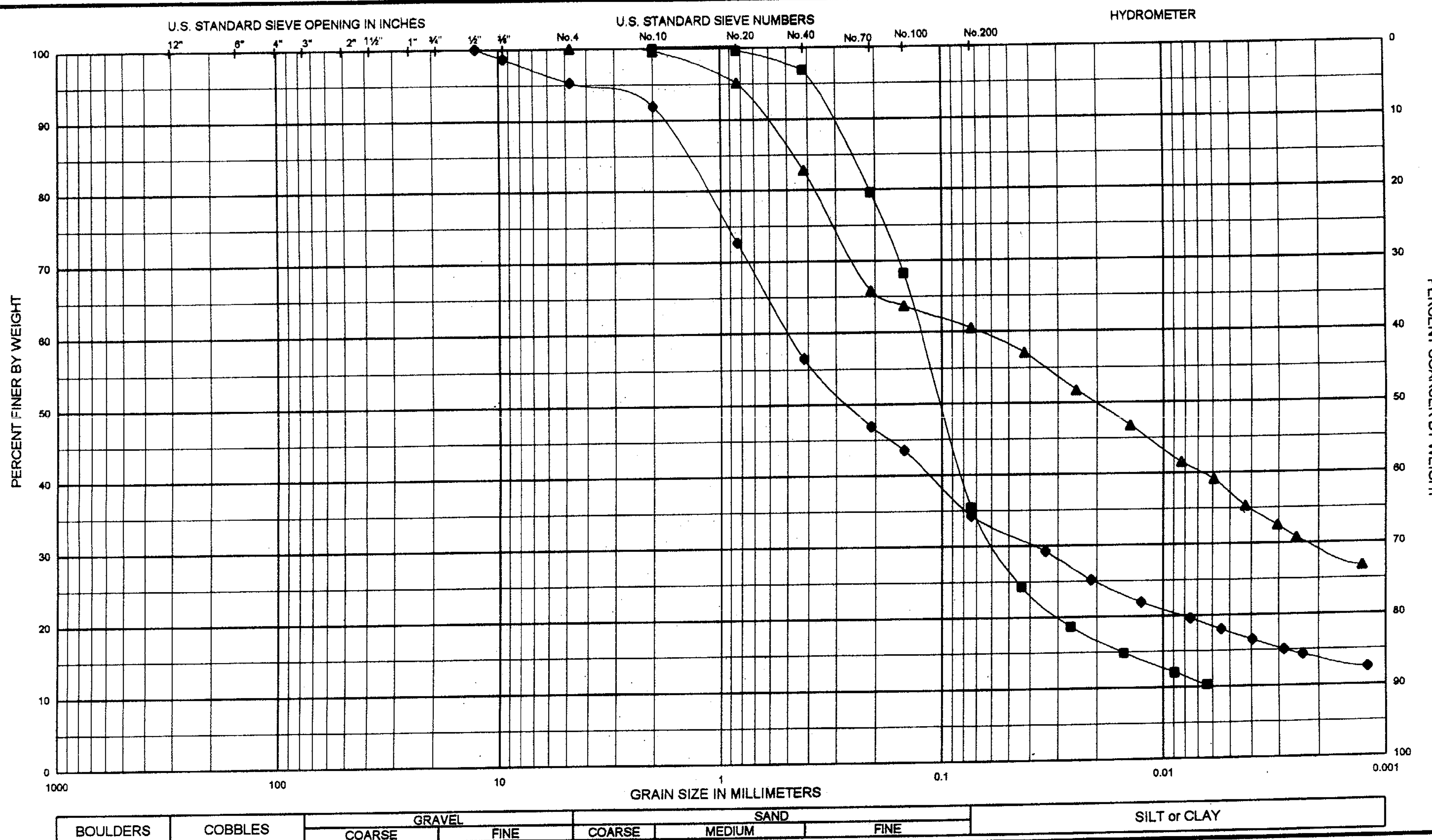
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
■	Jar-5-7	10.0-16.5	Silty sand (tr. mica) BC-3-7-9-2-2-2-3-3-1 (SM)	——	——	——	——
◆	Jar-8-10	17.5-24.0	Clayey sand (tr. gravel) BC-1-1-1-WOR/10'-1-2-1-4 (SC)	——	45	19	26
▲	Jar-11	25.0-26.5	Sandy fat clay BC-2-1-1 (CH)	——	69	20	49

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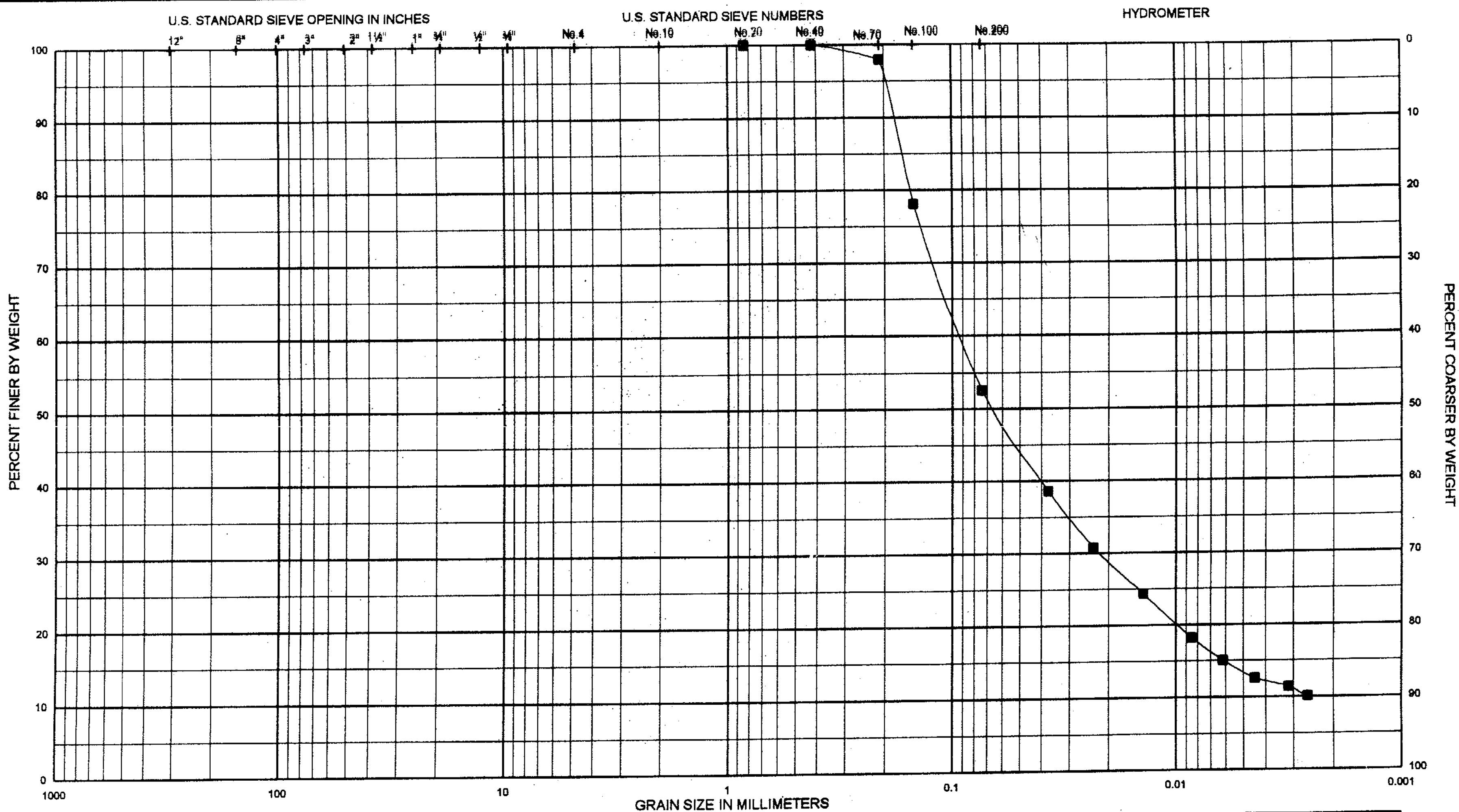
GRADATION CURVES



BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-5	5.0-6.5	Sandy silt (tr. mica) BC-5-6-6 (ML)	———		N.P.	

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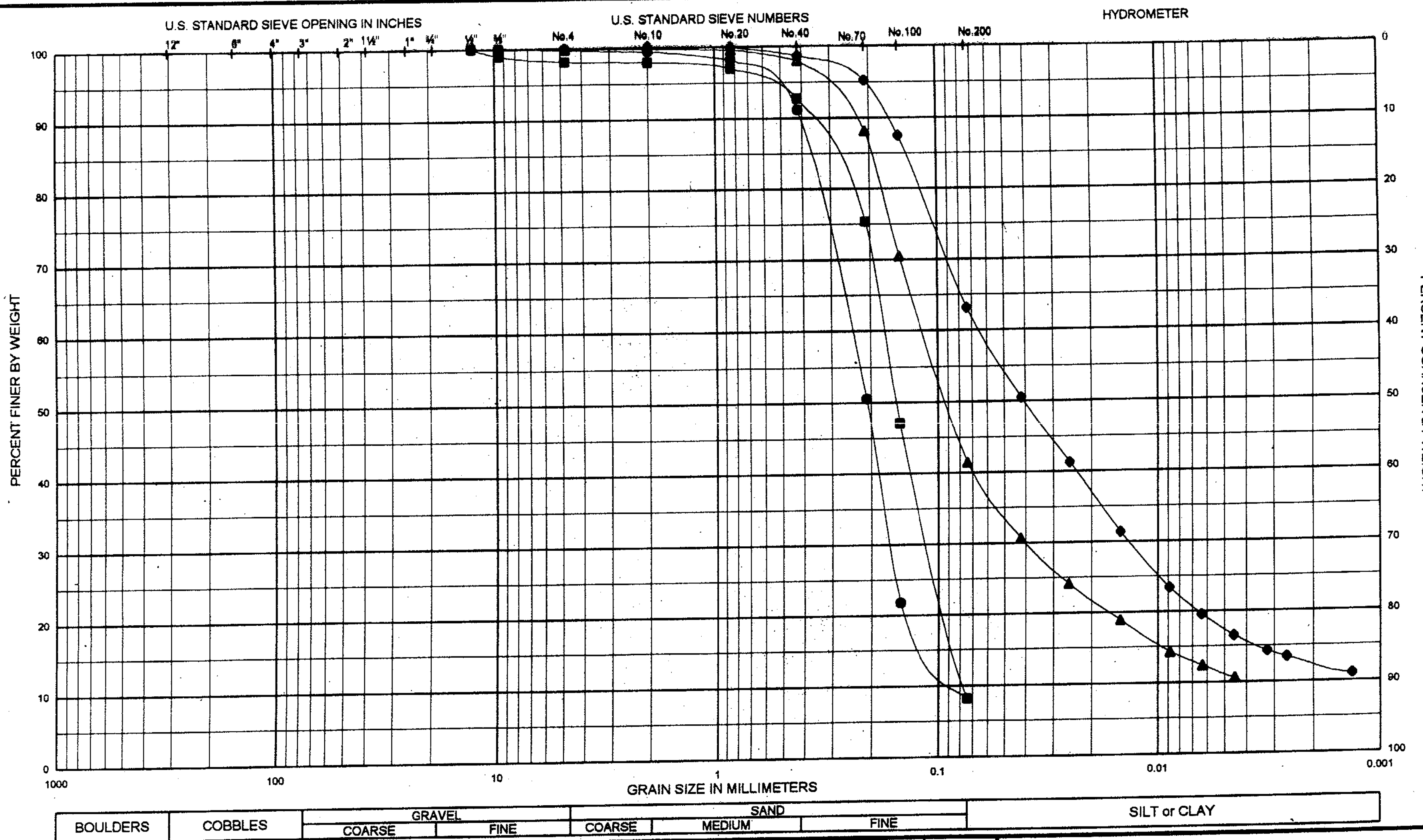
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-1.5	Poorly graded sand with silt (tr. gravel & mica (SP-SM)	——	——	——	——
—◆—	Jar-2	2.5-3.2	Sandy silt (tr. mica) Bc-1 (ML)	——	20	17	3
—▲—	Jar-3,4	3.2-6.5	Silty sand (tr. mica) Bc-5-3-4-4-5 (SM)	——	——	——	——
—●—	Jar-5	7.5-9.0	Poorly graded sand with silt (tr. mica) Bc-2-3-4 (SP-SM)	——	——	——	——

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AREA: Somerset County, MD

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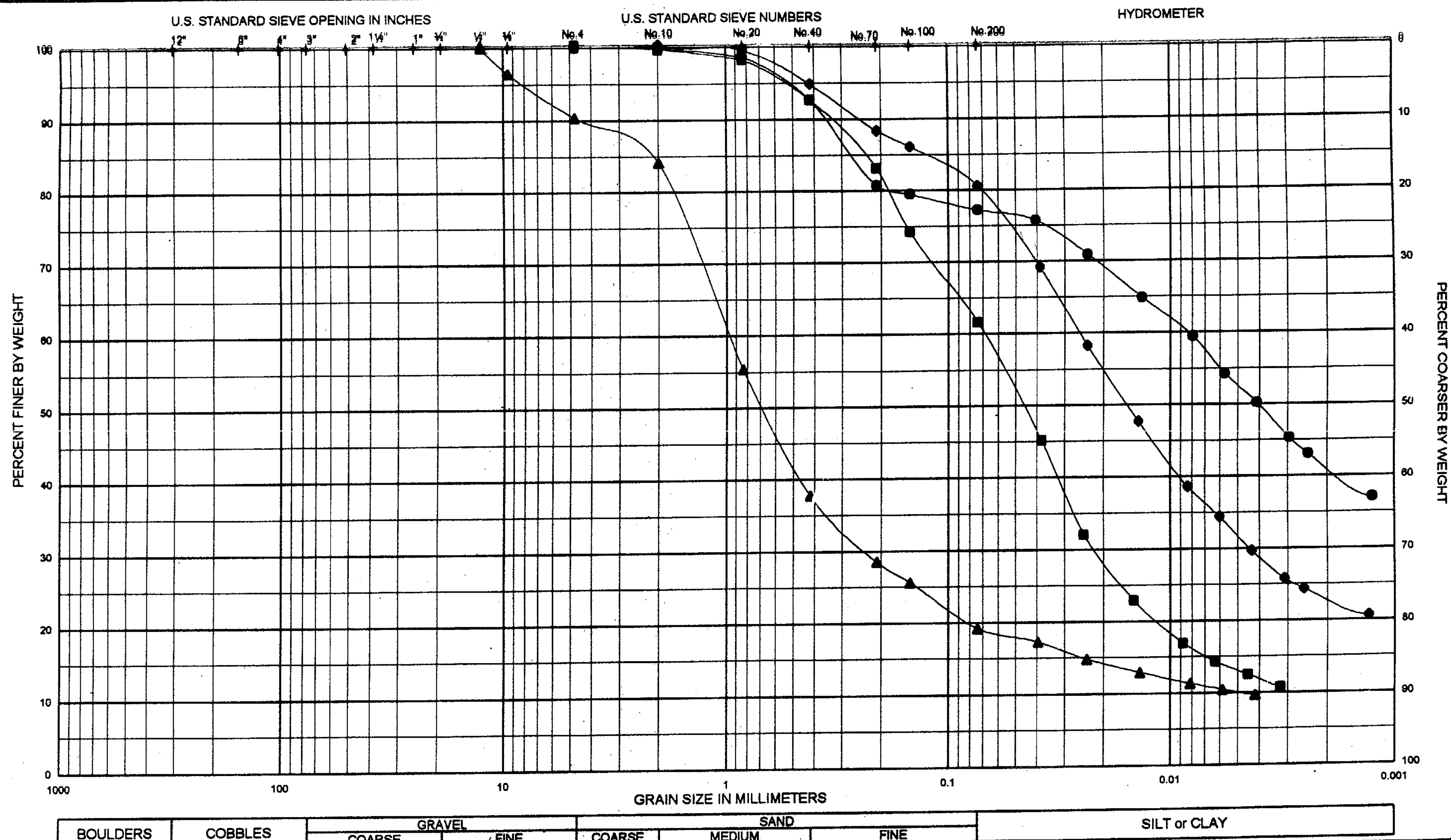
GRADATION CURVES

→ Bc-2-1-1



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-6	10.0-11.5	Sandy silt BC- 5-3-4	(ML)	——	——	——	——
—◆—	Jar-7	12.5-14.0	Lean clay with sand BC-3-2-2	(CL)	——	33	20	13
—▲—	Jar-10,11	20.0-24.0	Silty sand (tr. gravel) BC-1-1-1-1-4-2	(SM)	——	——	——	——
—●—	Jar-12	25.0-26.5	Fat clay with sand BC- 3-10-9	(CH)	——	72	21	51

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AREA: Somerset County, MD

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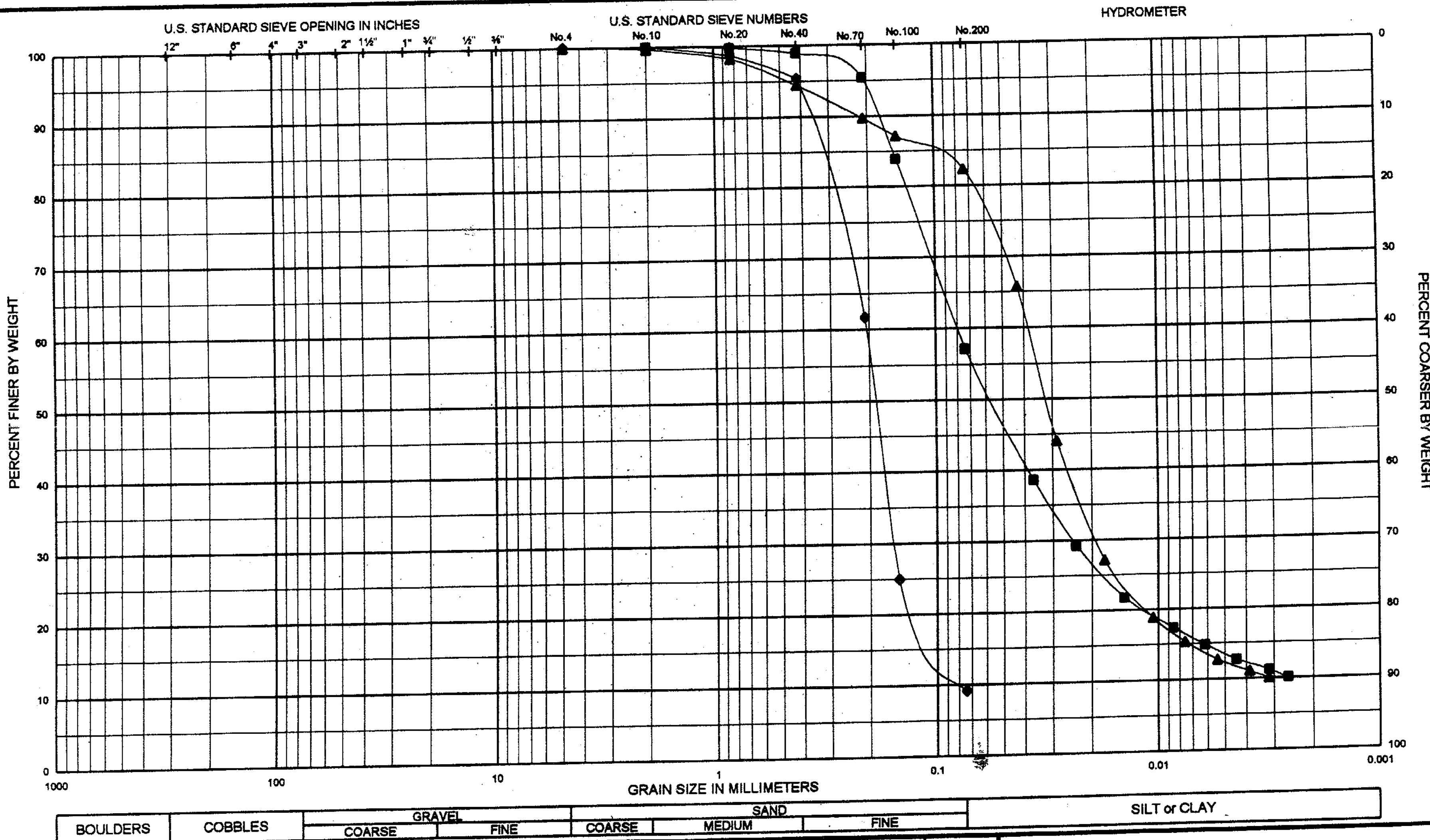
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
■	Jar-1	0.0-1.5	Sandy silt BC-1-1-3 (ML)	———	———	———	———
◆	Jar-3-5	3.4-8.1	Poorly graded sand with silt BC-1-6-7-2-24-1 (SP-SM)	———	———	———	———
▲	Jar-6	8.1-9.0	Silt with sand BC-1-2 (ML)	———	———	———	———

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AREA: Somerset County, MD

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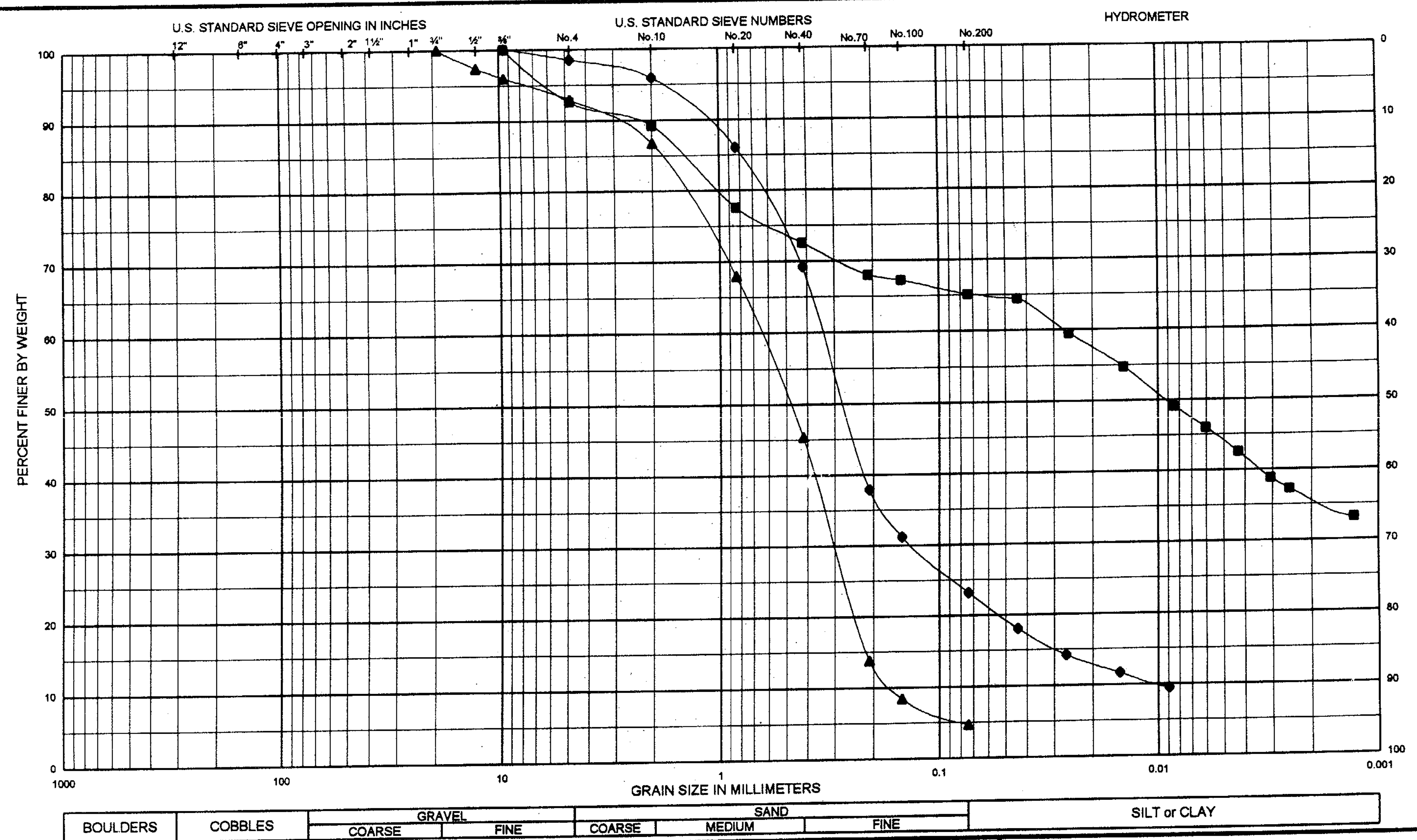
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-12	21.1-21.5	Sandy fat clay (tr. gravel) BC-1 (CH)	——	79	24	55
—◆—	Jar-14	22.9-24.0	Silty sand (tr. gravel) BC-6-10 (SM)	——	——	——	——
—▲—	Jar-15,16	25.0-26.5	Poorly graded sand (tr. gravel & mica) BC-5-10-15 (SP)	——	——	——	——

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Sheep Pen Gut

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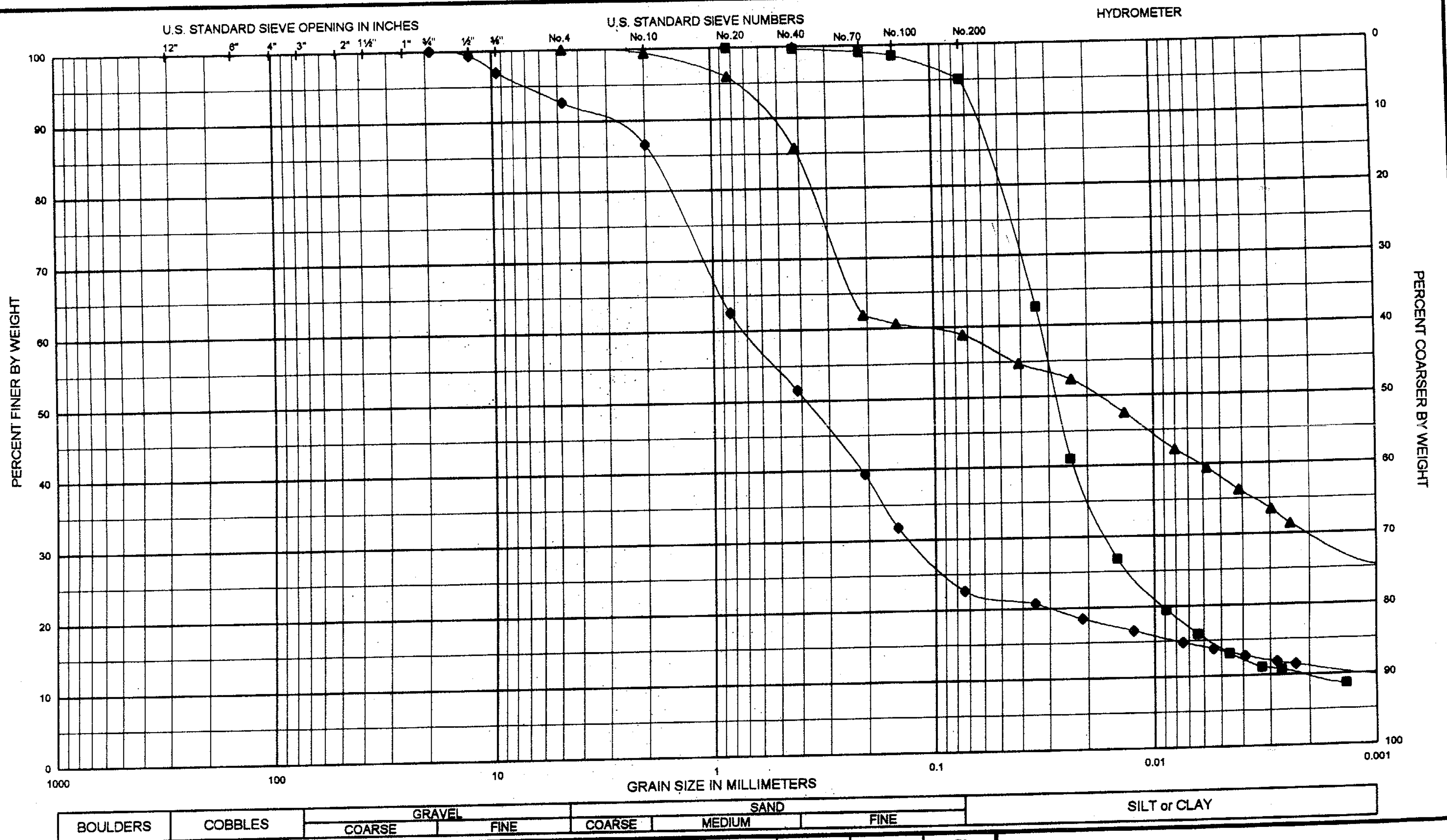
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-4	7.5-9.0	Micaceous silt (tr. sand) BC-2-2-3	(ML)	——	——	——	——
—◆—	Jar-8,9	17.5-21.5	Silty sand (tr. gravel) BC-WOH-WOH-1-2-1	(SM)	——	——	——	——
—▲—	Jar-10	22.5-24.0	Sandy fat clay BC-1-1-2	(CH)	——	55	17	38

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AREA: Somerset County, MD

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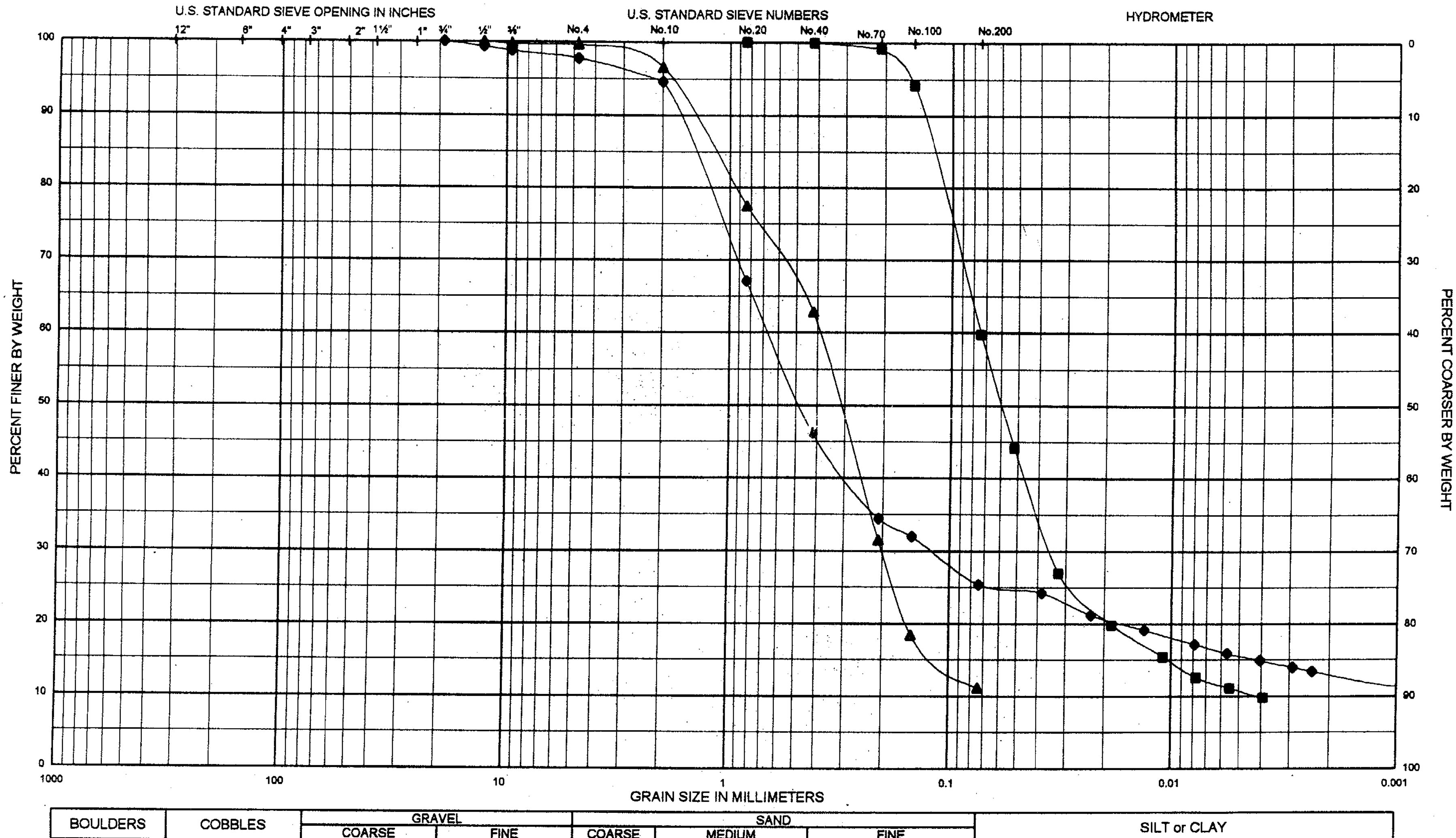

Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-2	2.5-4.0	Sandy silt (tr. mica)	(ML)	——	——	——	——
—◆—	Jar-7	15.0-16.5	Clayey sand (tr. gravel)	(SC)	——	43	19	24
—▲—	Jar-8	17.5-19.0	Well-graded sand with silt	(SW-SM)	——	——	——	——

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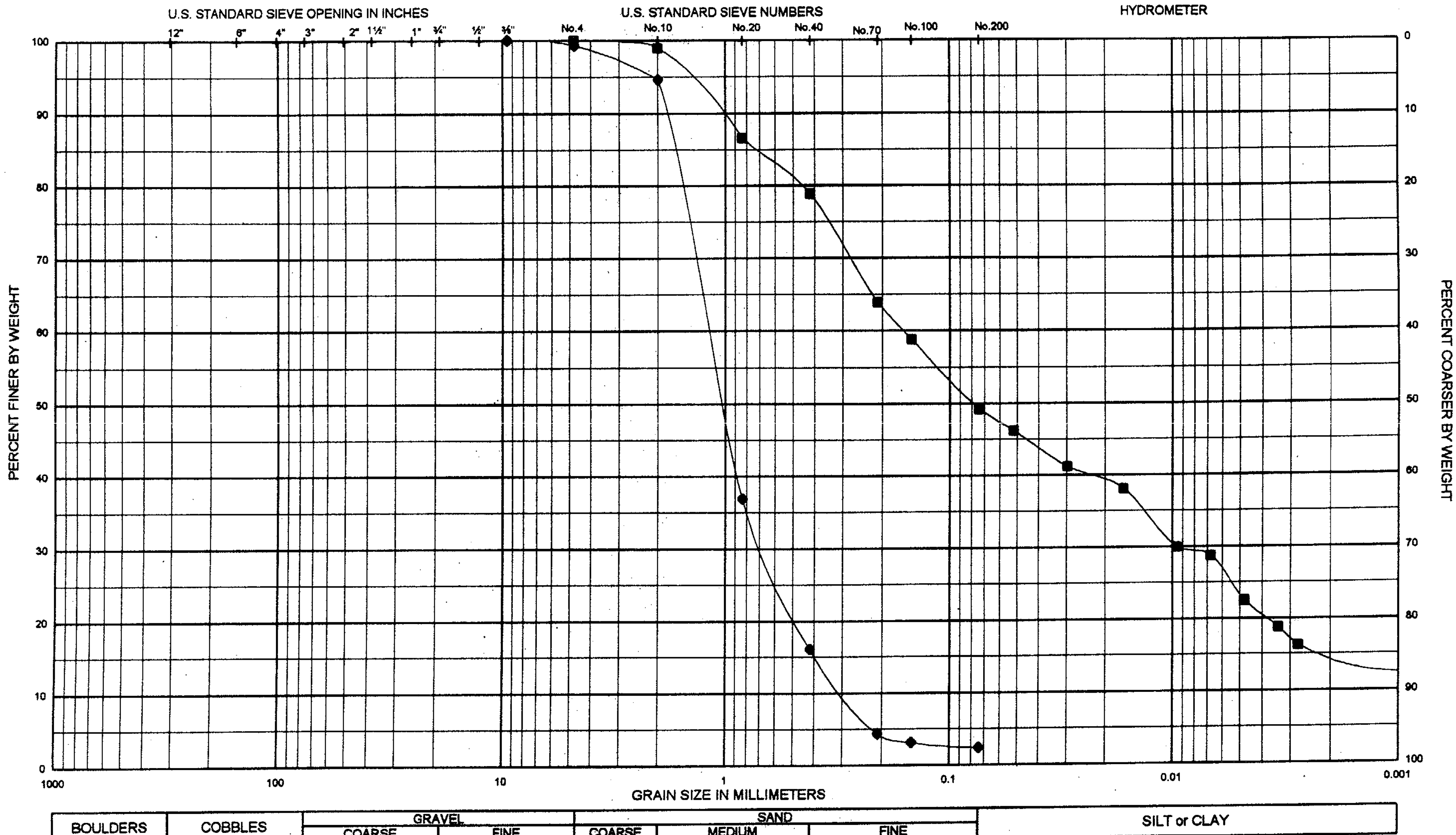

Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-12	25.0-25.4	Clayey sand	(SC-H)	———	55	18	37
—◆—	Jar-13	25.4-26.5	Poorly graded sand	(SP)	———	———	———	———

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Sheep Pen Gut

AREA: Somerset County, MD

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GRADATION CURVES

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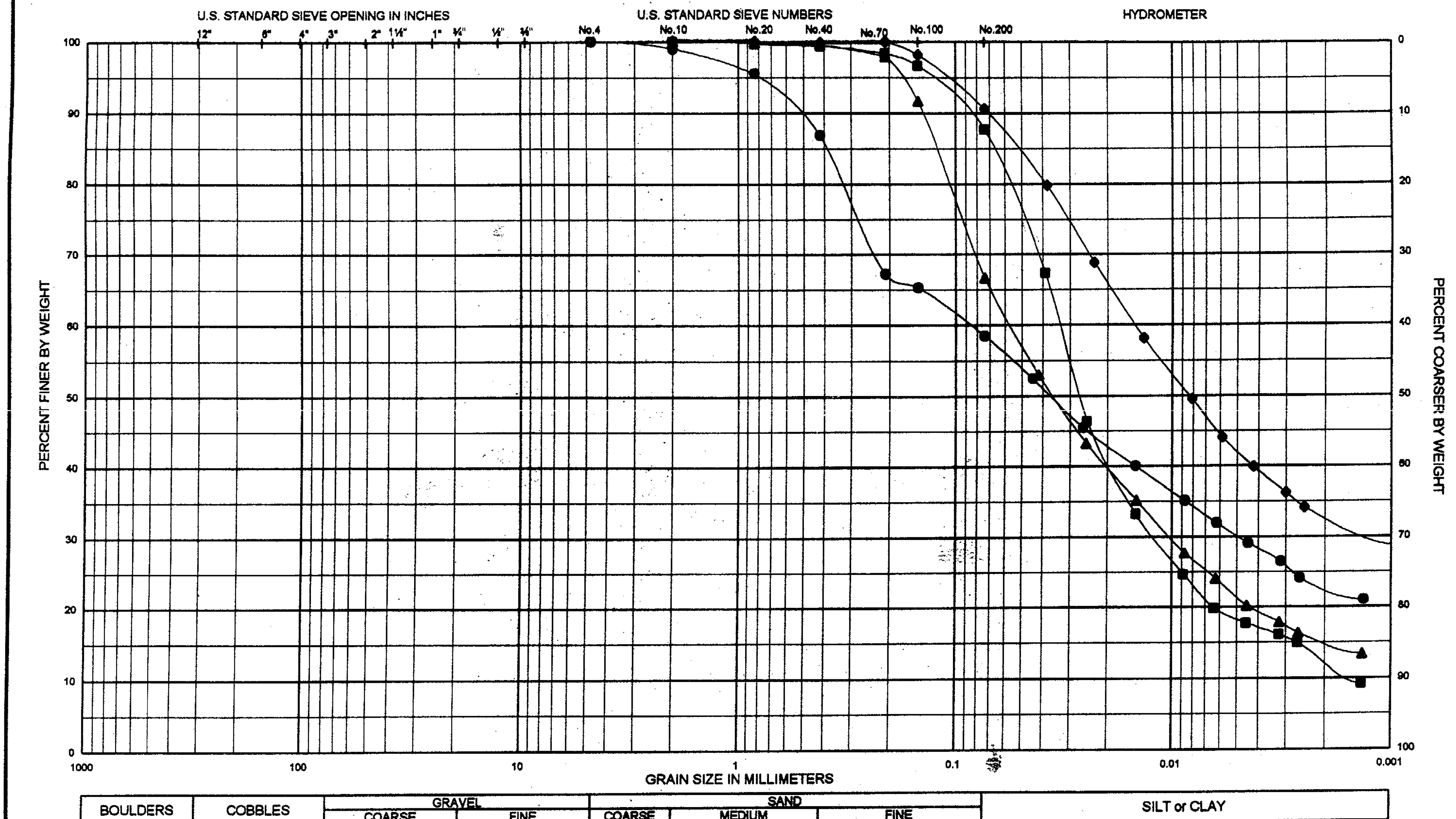

Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-4.0	Silt (tr. sand & mica)	(ML)	———	44	28	16
—◆—	Jar-3,4	5.0-9.0	Lean clay (tr. sand)	(CL)	———	44	22	22
—▲—	Jar-5-7	10.0-16.5	Sandy lean clay	(CL)	———	27	19	8
—●—	Jar-8-11	17.5-26.5	Sandy fat clay	(CH)	———	53	21	32

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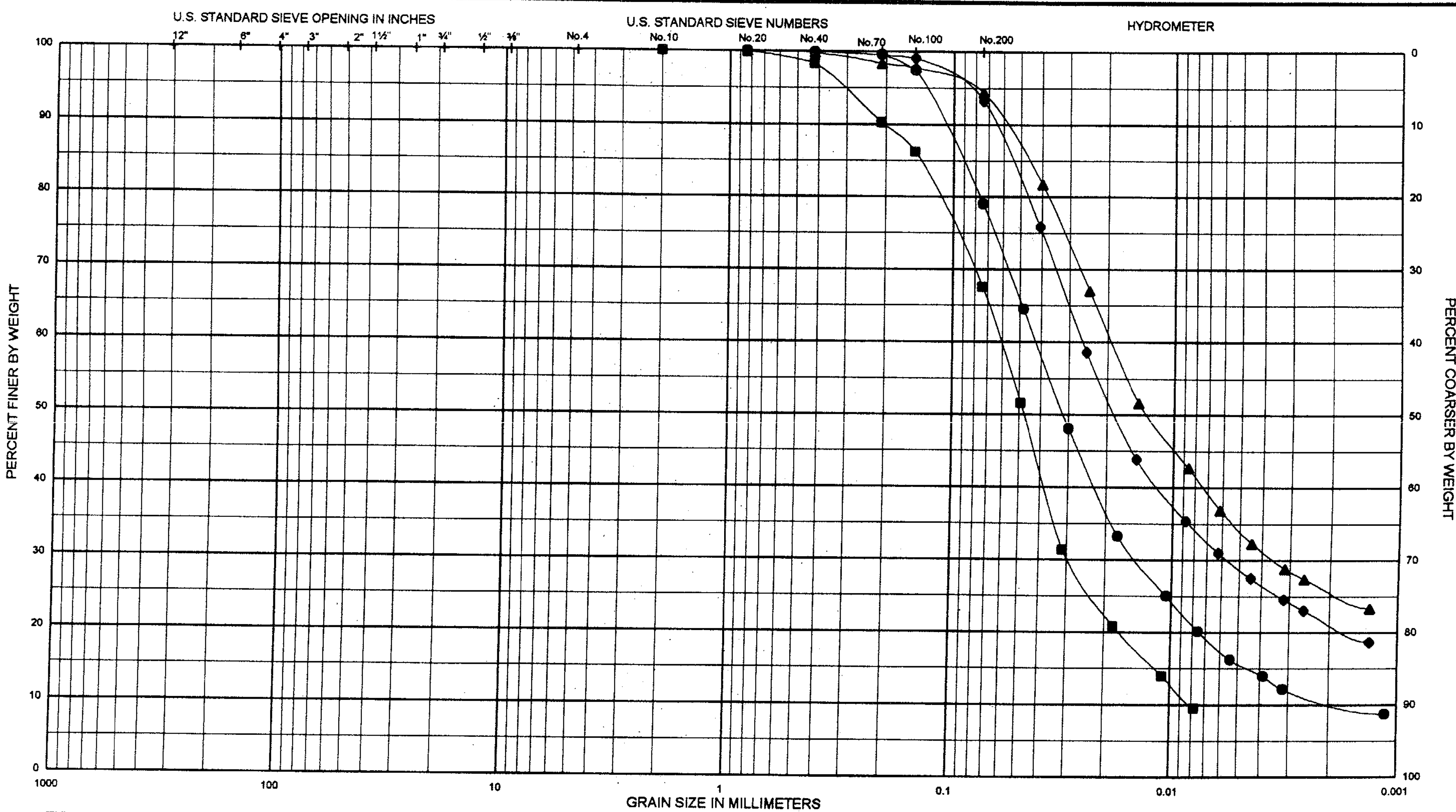

BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-1	0.0-1.5	Sandy silt (tr. mica)	(ML)	—	—	—	—
◆	Jar-2	2.5-4.0	Lean clay (tr. sand & mica)	(CL)	—	—	—	—
▲	Jar-3,4	5.0-9.0	Fat clay (tr. sand)	(CH)	—	—	—	—
●	Jar-5	10.0-11.5	Lean clay with sand	(CL)	—	—	—	—

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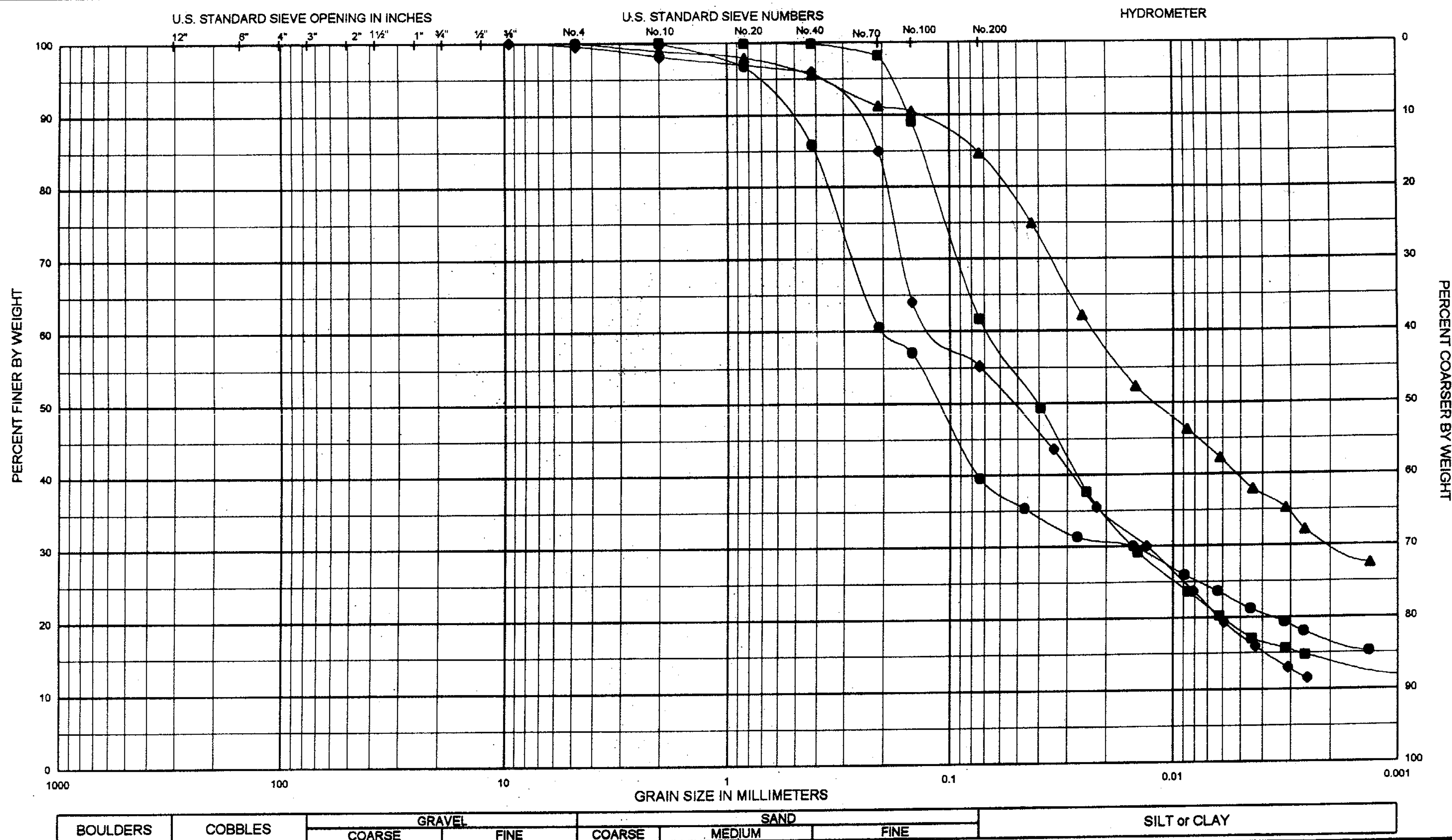
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-6	12.5-14.0	Sandy lean clay (CL)	—	—	—	—
—◆—	Jar-8	15.7-16.5	Sandy lean clay (CL)	—	—	—	—
—▲—	Jar-9-11	17.5-24.0	Fat clay with sand (CH)	—	54	24	30
—●—	Jar-12	25.0-26.5	Clayey sand (SC)	—	—	—	—

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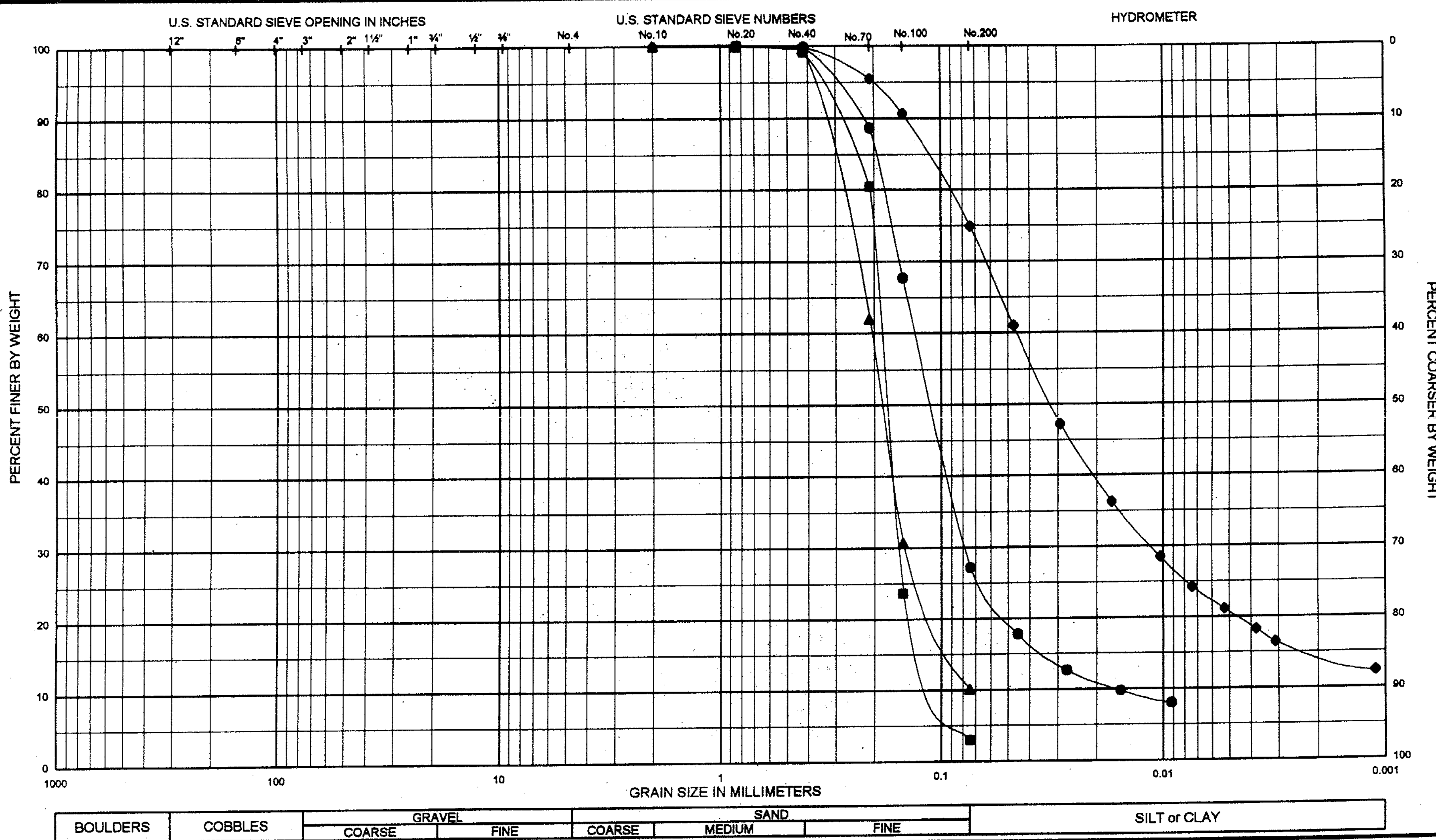
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-1	0.0-1.5	Poorly graded sand	(SP)	—	—	—	—
◆	Jar-2,3	2.5-6.5	Silt with sand (tr. mica)	(ML)	—	—	—	—
▲	Jar-4	7.5-9.0	Poorly graded sand with silt (tr. mica)	(SP-SM)	—	—	—	—
●	Jar-5	10.0-11.5	Silty sand	(SM)	—	—	—	—

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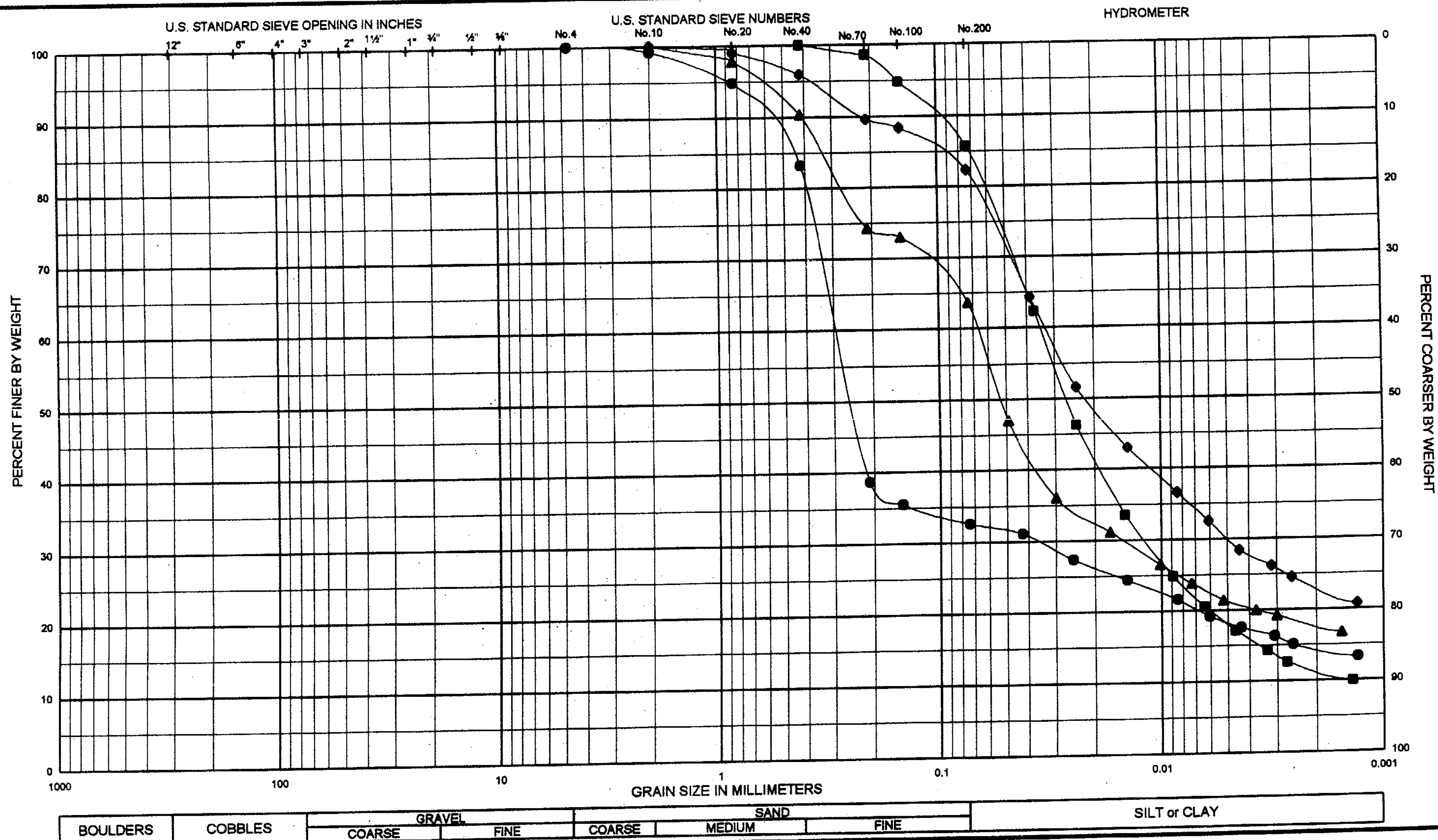

Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-6	12.5-14.0	Silt (tr. sand & mica)	(ML)	——	——	——	——
—◆—	Jar-7,8	15.0-19.0	Lean clay with sand	(CL)	——	——	——	——
—▲—	Jar-9	20.0-21.5	Sandy lean clay (tr. mica)	(CL)	——	47	21	26
—●—	Jar-11	25.0-26.5	Clayey sand	(SC)	——	——	——	——

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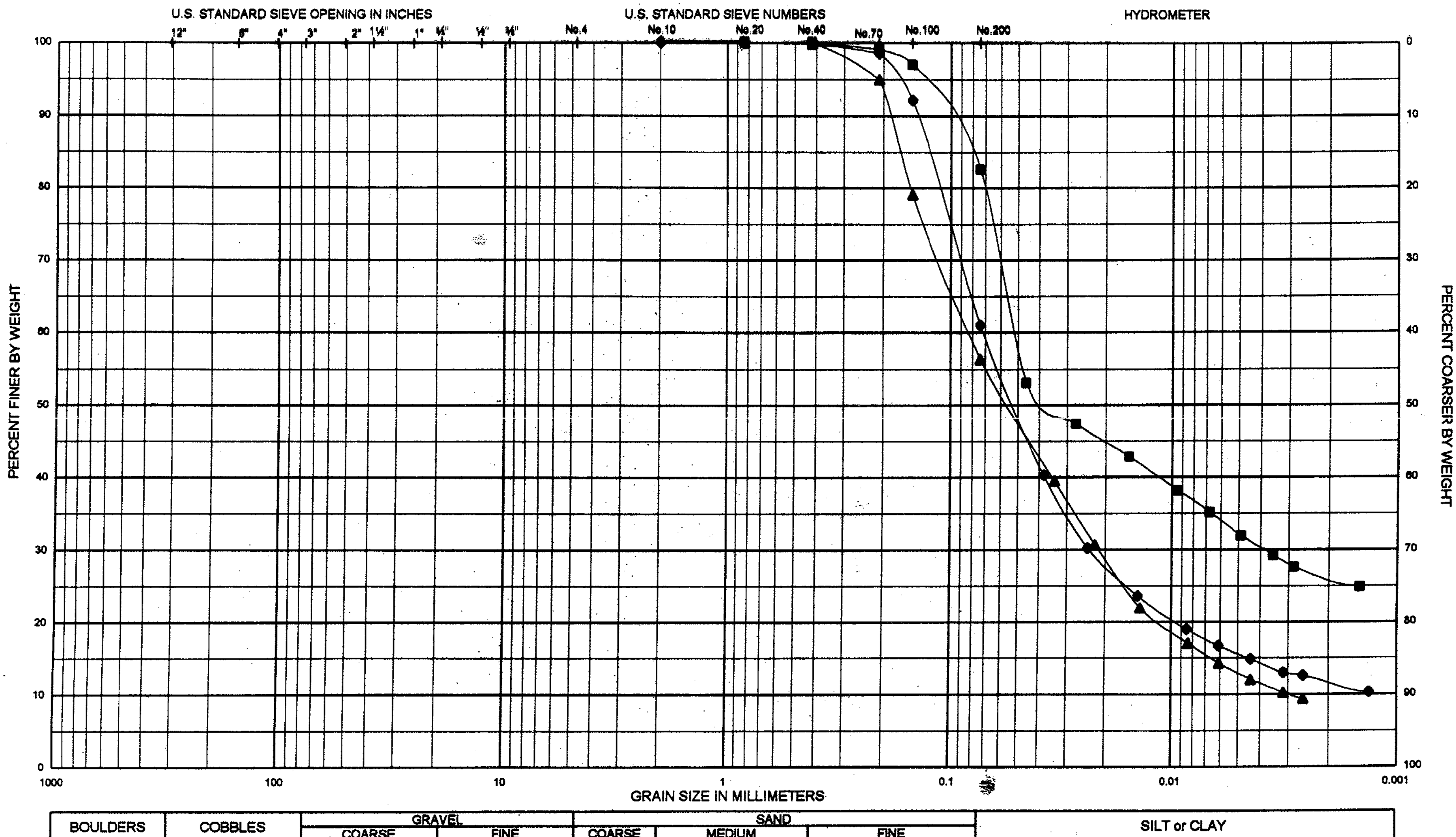
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-4.0	Lean clay with sand (tr. mica)	(CL)	——	28	17	11
—◆—	Jar-3	5.0-6.5	Sandy silt (tr. mica)	(ML)	——	——	——	——
—▲—	Jar-4	7.5-9.0	Sandy silt (tr. mica)	(ML)	——	——	——	——

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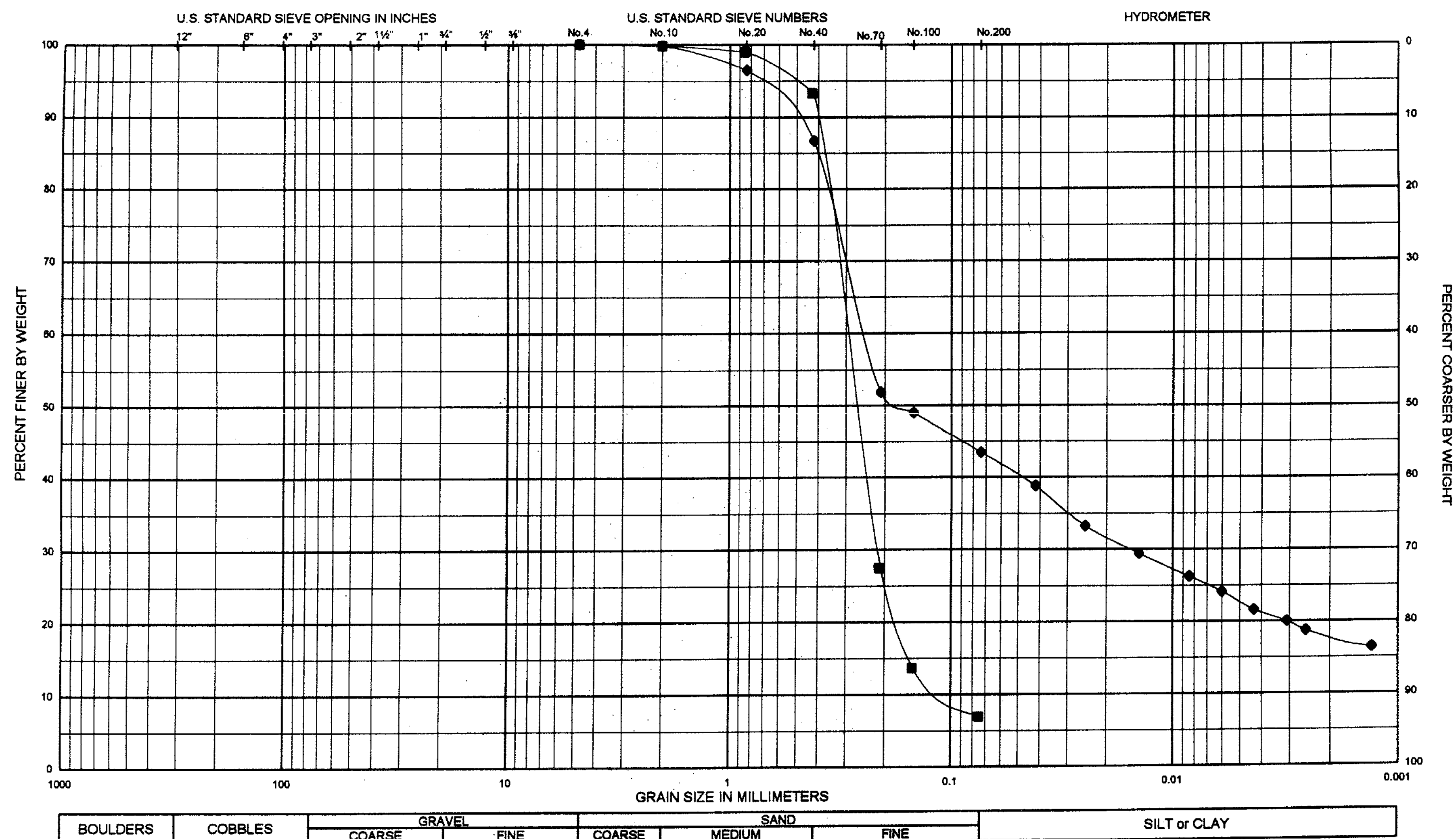

Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-5-7	10.0-16.5	Poorly graded sand with silt (tr. mica)	(SP-SM)	——	——	——	——
—◆—	Jar-8-11	17.5-26.5	Clayey sand	(SC)	——	43	18	25

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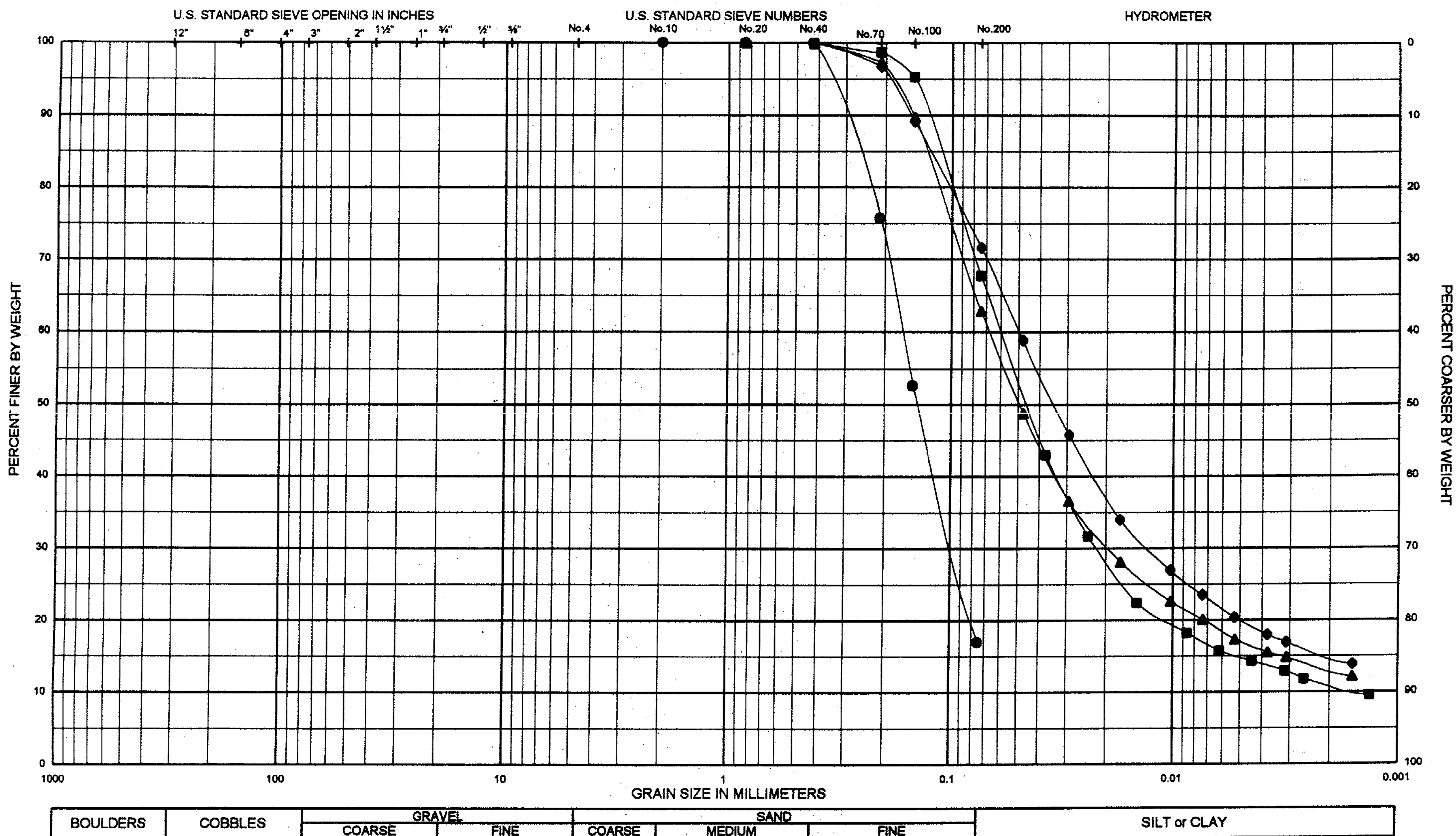
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	1.1-1.5	Sandy silt (tr. mica) (ML)	——	——	——	——
—◆—	Jar-2	2.5-4.0	Lean clay with sand (tr. mica) (CL)	——	——	——	——
—▲—	Jar-3,4	5.0-9.0	Sandy silt (tr. mica) (ML)	——	21	18	3
—●—	Jar-5	10.0-11.5	Silty sand (tr. mica) (SM)	——	——	——	——

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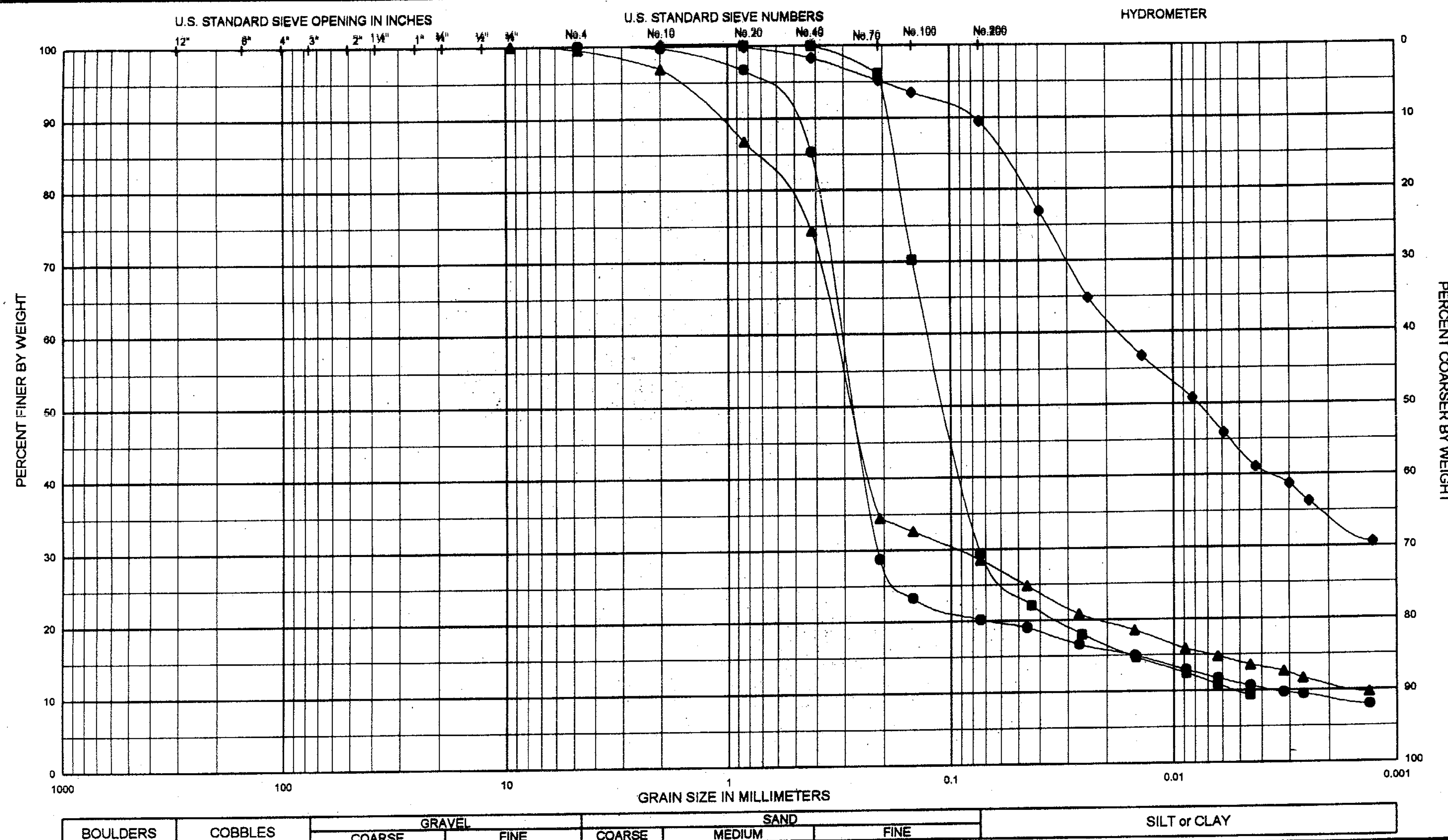
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-6	12.5-14.0	Silty sand (tr. mica)	(SM)	——	——	——	——
◆	Jar-7,8	15.0-19.0	Fat clay (tr. sand & mica)	(CH)	——	——	——	——
▲	Jar-9,10	20.0-24.0	Clayey sand (tr. mica)	(SC)	——	——	——	——
●	Jar-11	25.0-26.5	Silty sand (tr. mica)	(SM)	——	——	——	——

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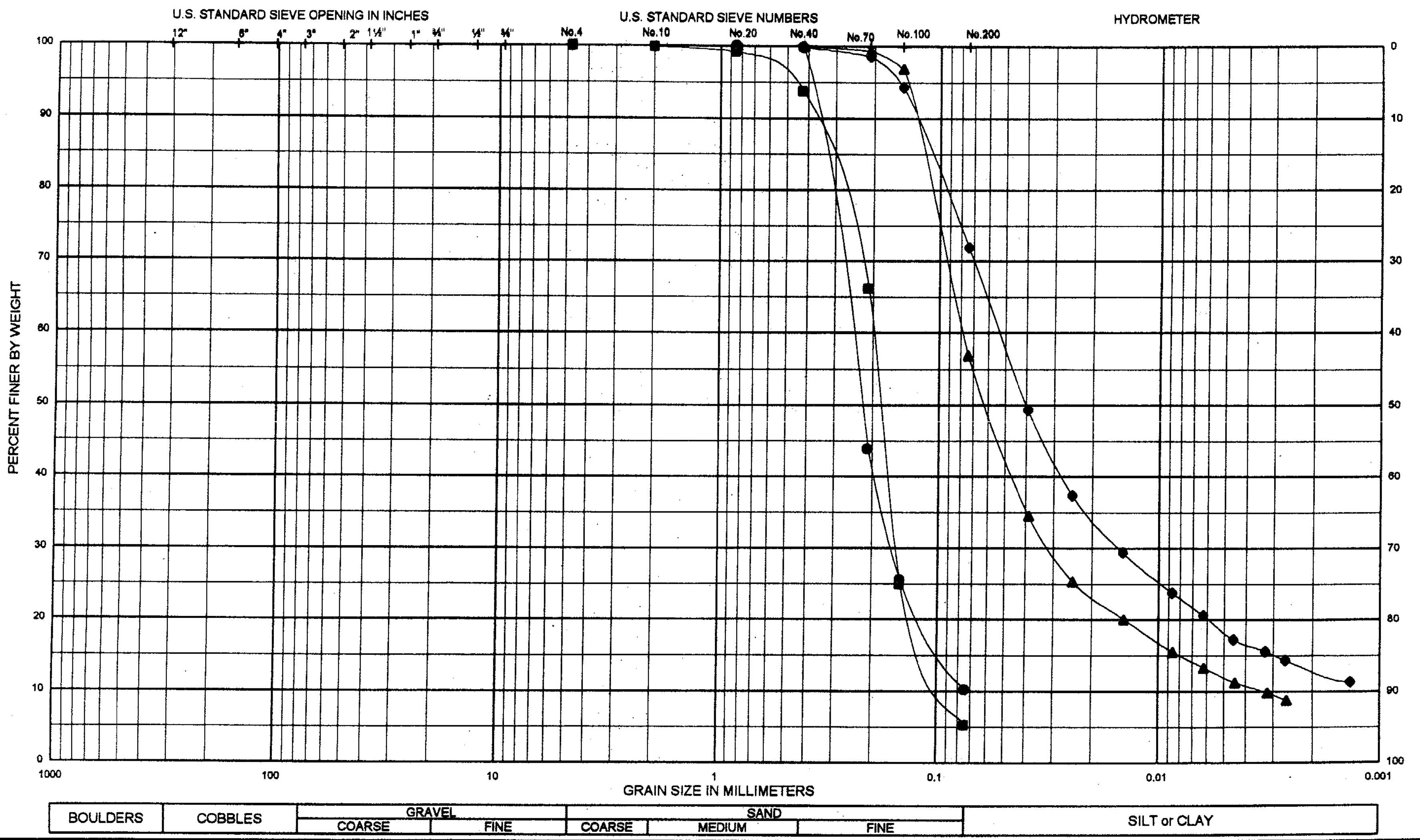
GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-1	0.0-0.5	Poorly graded sand with silt	(SP-SM)	—	—	—	—
◆	Jar-2,3	0.5-4.0	Lean clay with sand (tr. mica)	(CL)	—	—	—	—
▲	Jar-4	5.0-6.5	Micaceous sandy silt	(ML)	—	—	—	—
●	Jar-5,6	7.5-11.5	Poorly graded sand with silt (tr. mica)	(SP-SM)	—	—	—	—

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GRADATION CURVES

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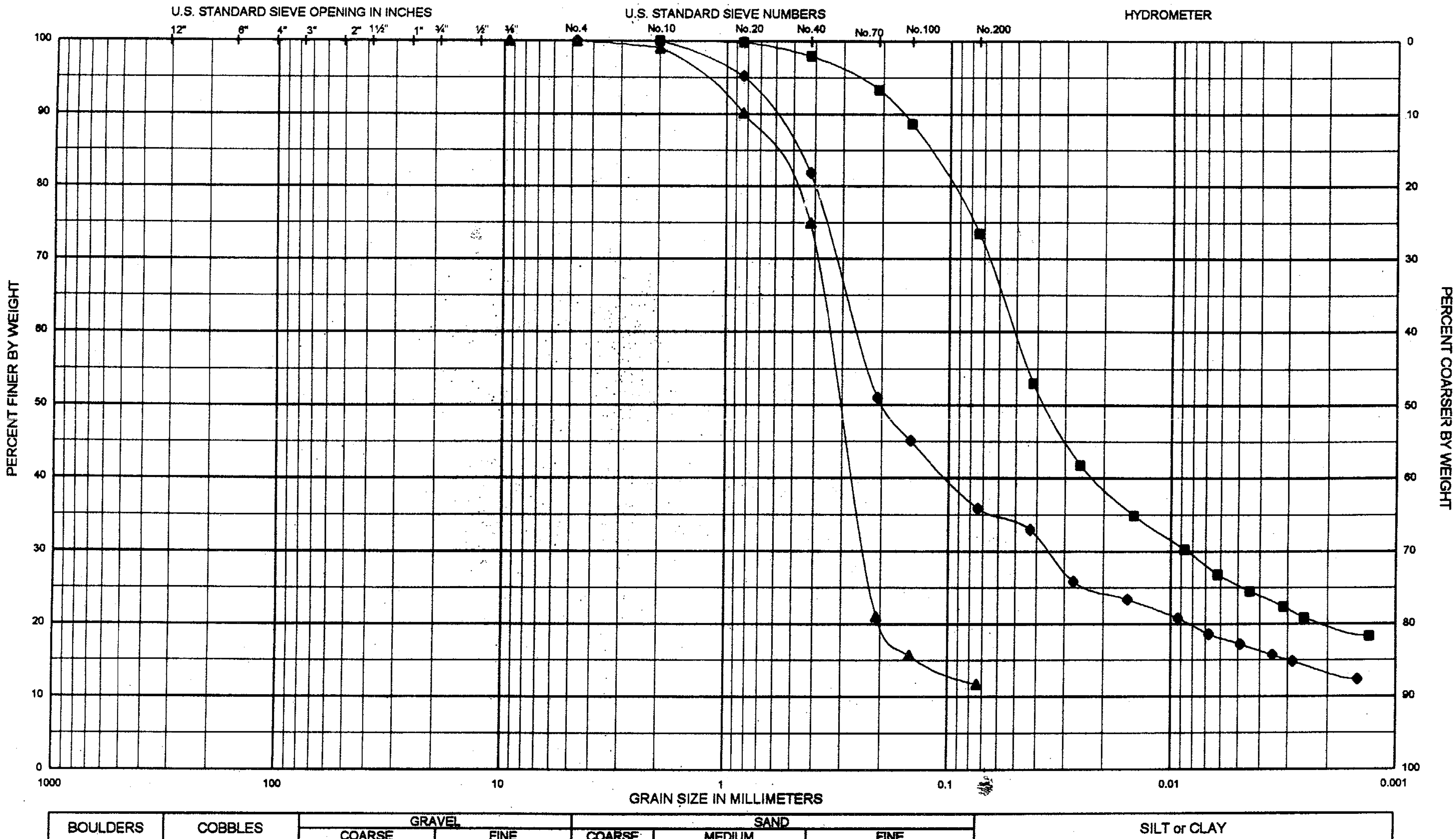
Boring No.: DH-28 Sht. 1 of 2

DATE: Jan 1999



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-7,8	12.5-16.5	Lean clay with sand (tr. mica)	(CL)	———	39	21	18
—◆—	Jar-9,10	17.5-21.5	Clayey sand (tr. mica)	(SC)	———	38	18	20
—▲—	Jar-11,12	22.5-26.5	Poorly graded sand with silt (tr. mica)	(SP-SM)	———	———	———	———

PROJECT: Smith Island Environmental Restoration
Northern Coves

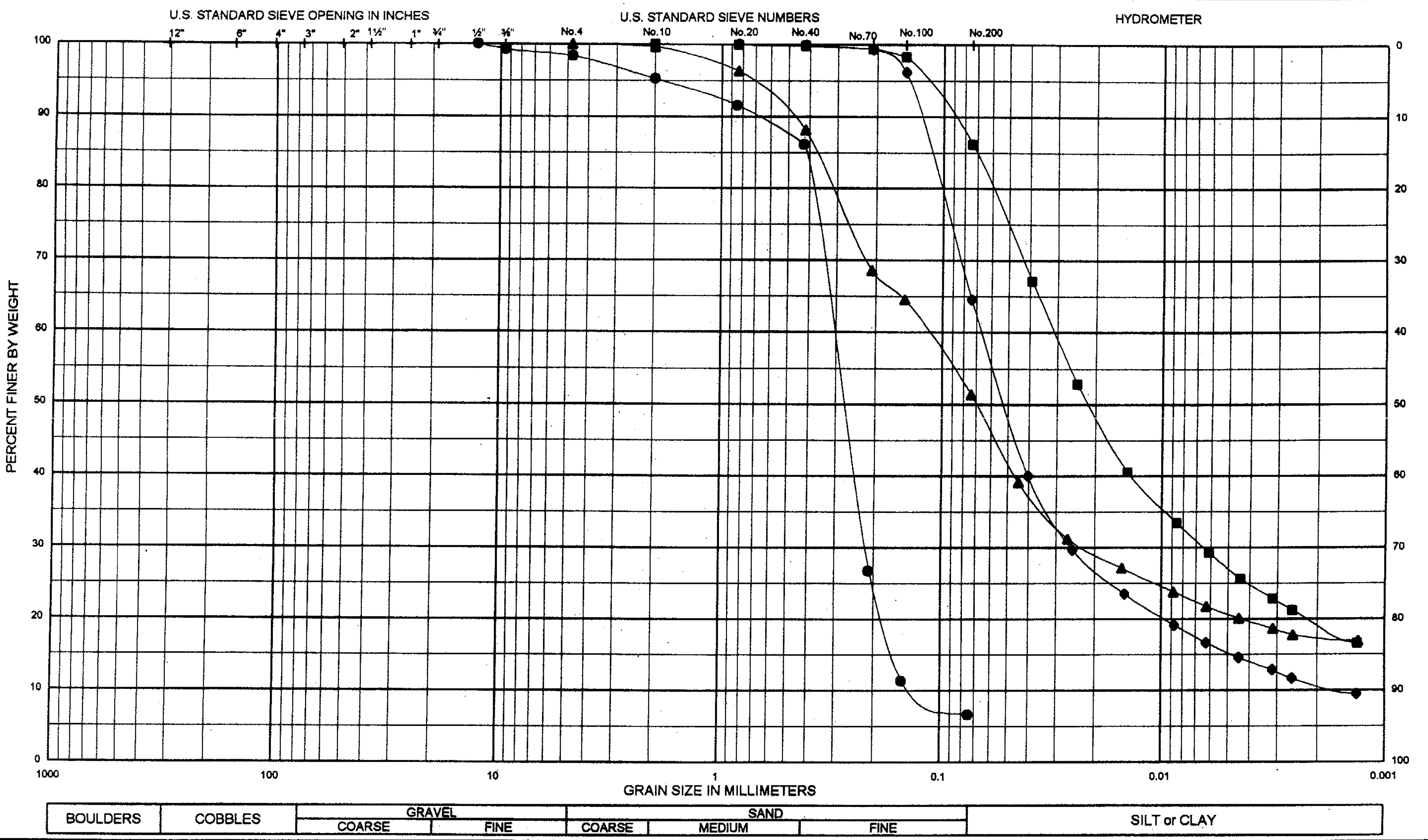
AREA: Somerset County, MD

Boring No.: DH-28 Sht. 2 of 2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-1-3	0.0-4.0	Lean clay (tr. sand)	(CL)	——	33	20	13
◆	Jar-4,5	5.0-9.0	Sandy silt (tr. mica)	(ML)	——	——	——	——
▲	Jar-6-9	10.0-18.1	Sandy lean clay (tr. mica)	(CL)	——	40	20	20
●	Jar-10,11	18.1-21.5	Poorly graded sand with silt (tr. gravel)	(SP-SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Northern Coves

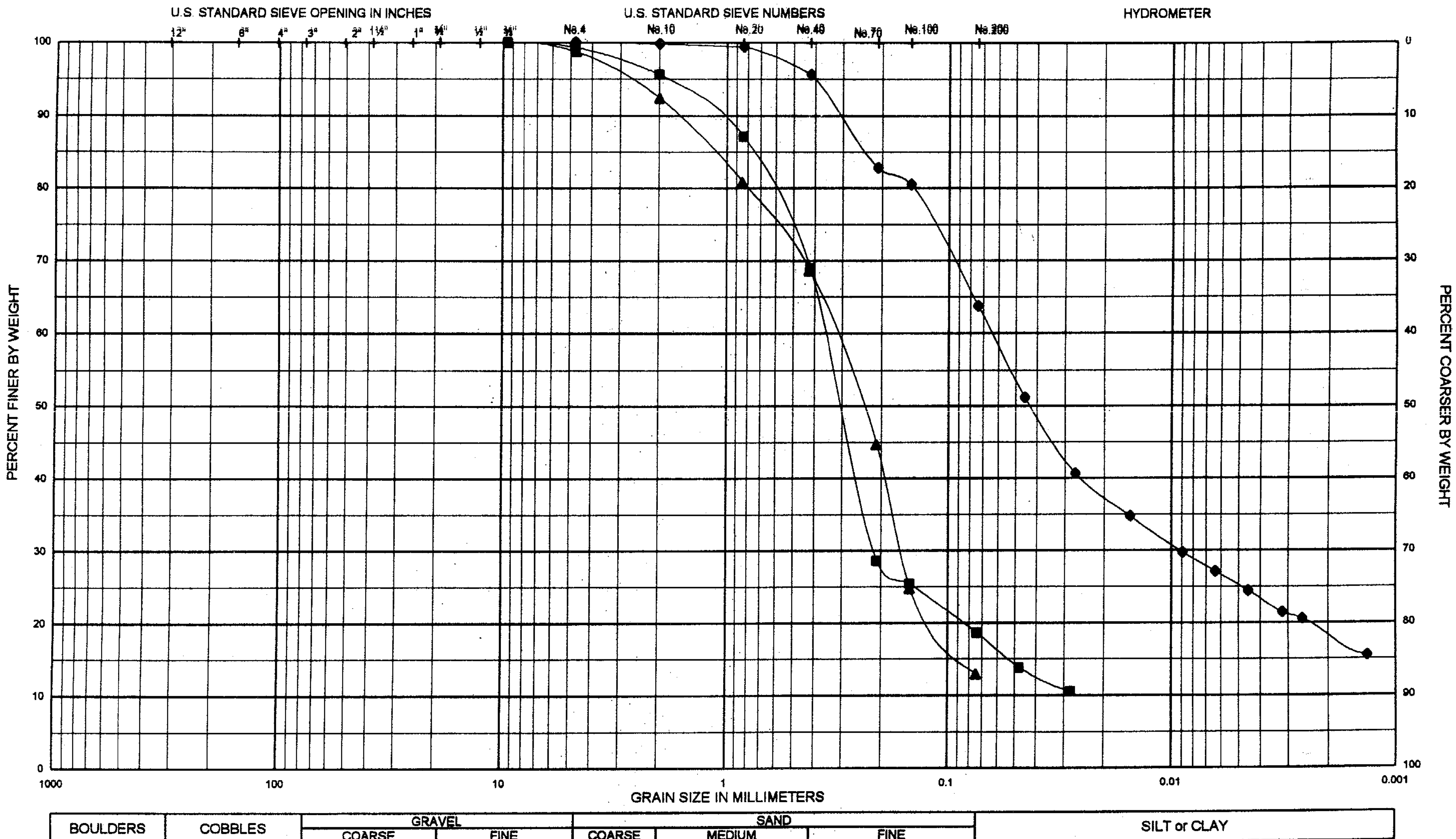
AREA: Somerset County, MD

Boring No.: DH-29 Sht. 1 of 2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-12	22.5-23.4	Silty sand	(SM)	—	—	—	—
◆	Jar-13	23.4-24.0	Sandy lean clay (tr. mica)	(CL)	—	43	20	23
▲	Jar-14-16	25.0-26.5	Silty sand (tr. gravel)	(SM)	—	—	—	—

PROJECT: Smith Island Environmental Restoration
Northern Coves

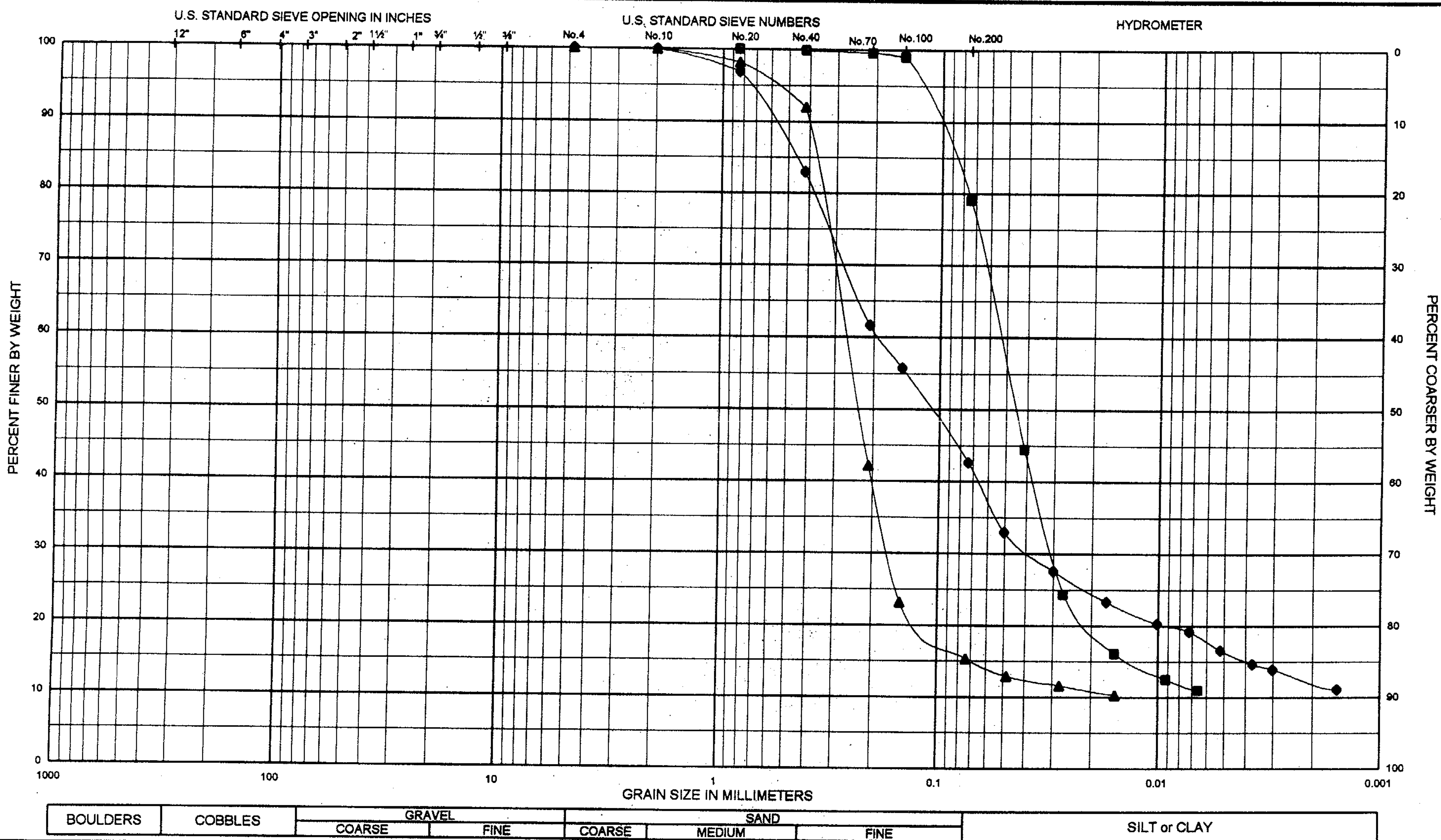
AREA: Somerset County, MD

Boring No.: DH-29 Sht. 2 of 2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-1-3	0.0-6.5	Silt with sand (tr. mica)	(ML)	——	——	——	——
◆	Jar-4-6	7.5-13.5	Clayey sand (tr. mica)	(SC)	——	39	17	22
▲	Jar-7,8	13.5-16.5	Silty sand (tr. mica)	(SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Northern Coves

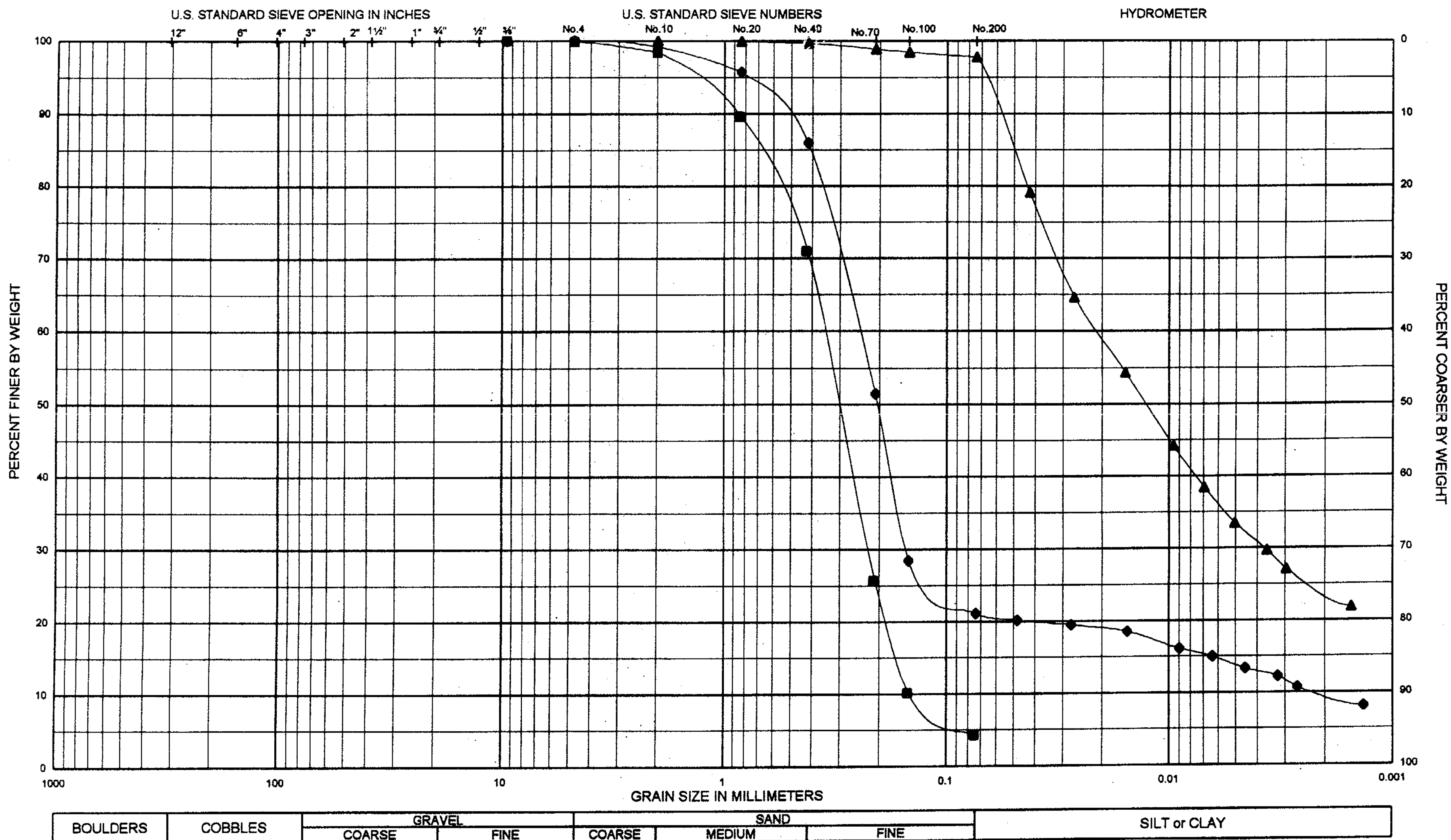
AREA: Somerset County, MD

Boring No.: DH-30 Sht. 1 of 2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
—■—	Jar-9-11	17.5-21.5	Poorly graded sand (tr. mica)	(SP)	———	———	———	———
—◆—	Jar-12	22.5-24.0	Clayey sand (tr. mica)	(SC)	———	———	———	———
—▲—	Jar-13	25.0-26.5	Fat clay (tr. sand)	(CH)	———	98	30	68

PROJECT: Smith Island Environmental Restoration
Northern Coves

AREA: Somerset County, MD

Boring No.: DH-30 Sht. 2 of 2

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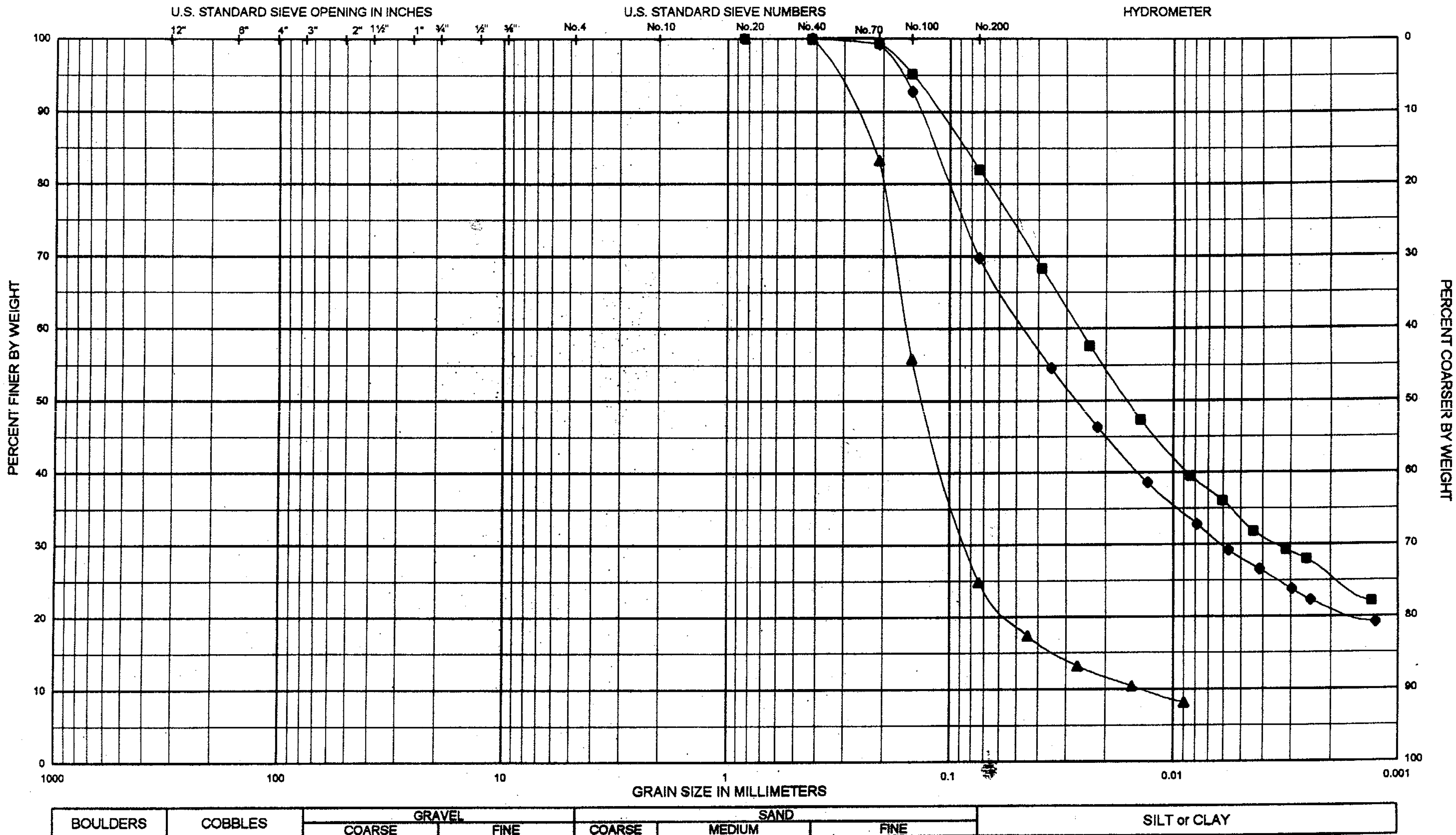
ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-1	0.0-1.5	Fat clay with sand	(CH)	——	——	——	——
◆	Jar-2	2.5-4.0	Sandy lean clay (tr. mica)	(CL)	——	——	——	——
▲	Jar-3-5	5.0-11.5	Silty sand (tr. mica)	(SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Northern Coves

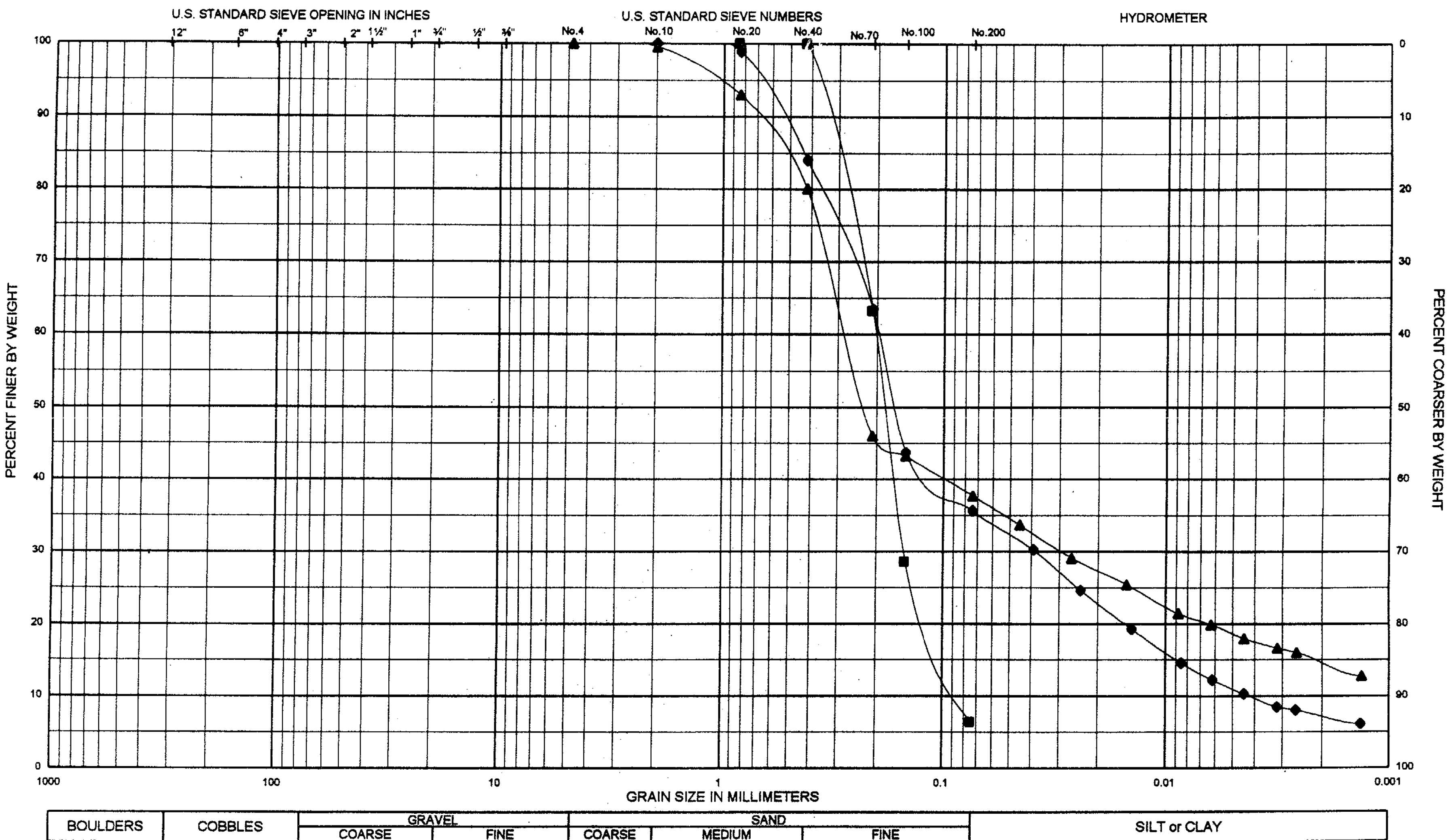
AREA: Somerset County, MD

Boring No.: DH-26 Sht. 1 of 2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification		Nat w%	LL	PL	PI
■	Jar-6,7	12.5-16.5	Poorly graded sand with silt (tr. mica)	(SP-SM)	——	——	——	——
◆	Jar-8	17.5-18.2	Silty sand (tr. mica)	(SM)	——	——	——	——
▲	Jar-9-12	18.2-26.5	Clayey sand	(SC)	——	48	20	28

PROJECT: Smith Island Environmental Restoration
Northern Coves

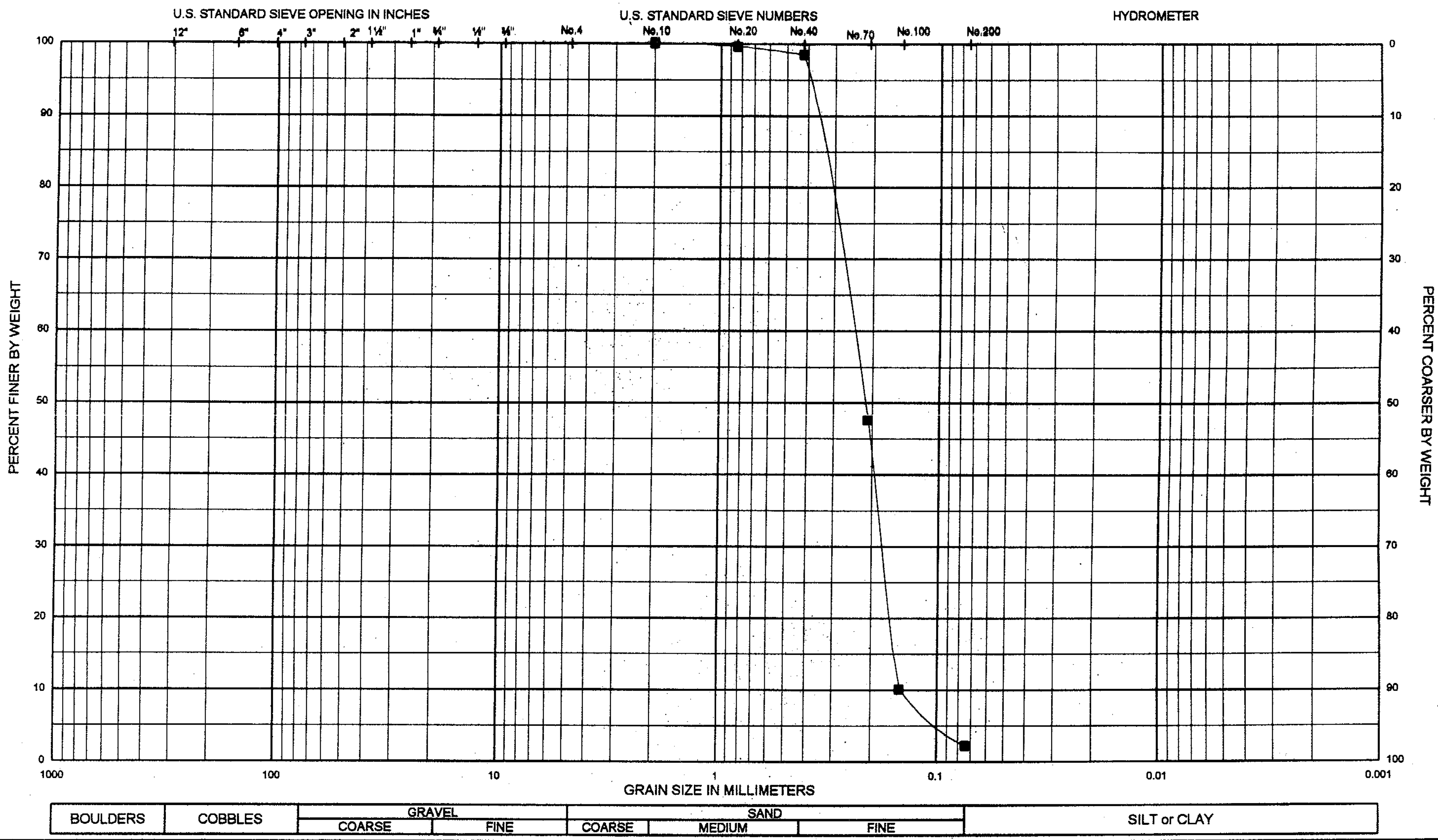
AREA: Somerset County, MD

Boring No.: DH-26 Sht. 2 of 2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-3.7	Poorly graded sand Cu: 1.6 Cc = .81 (SP)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

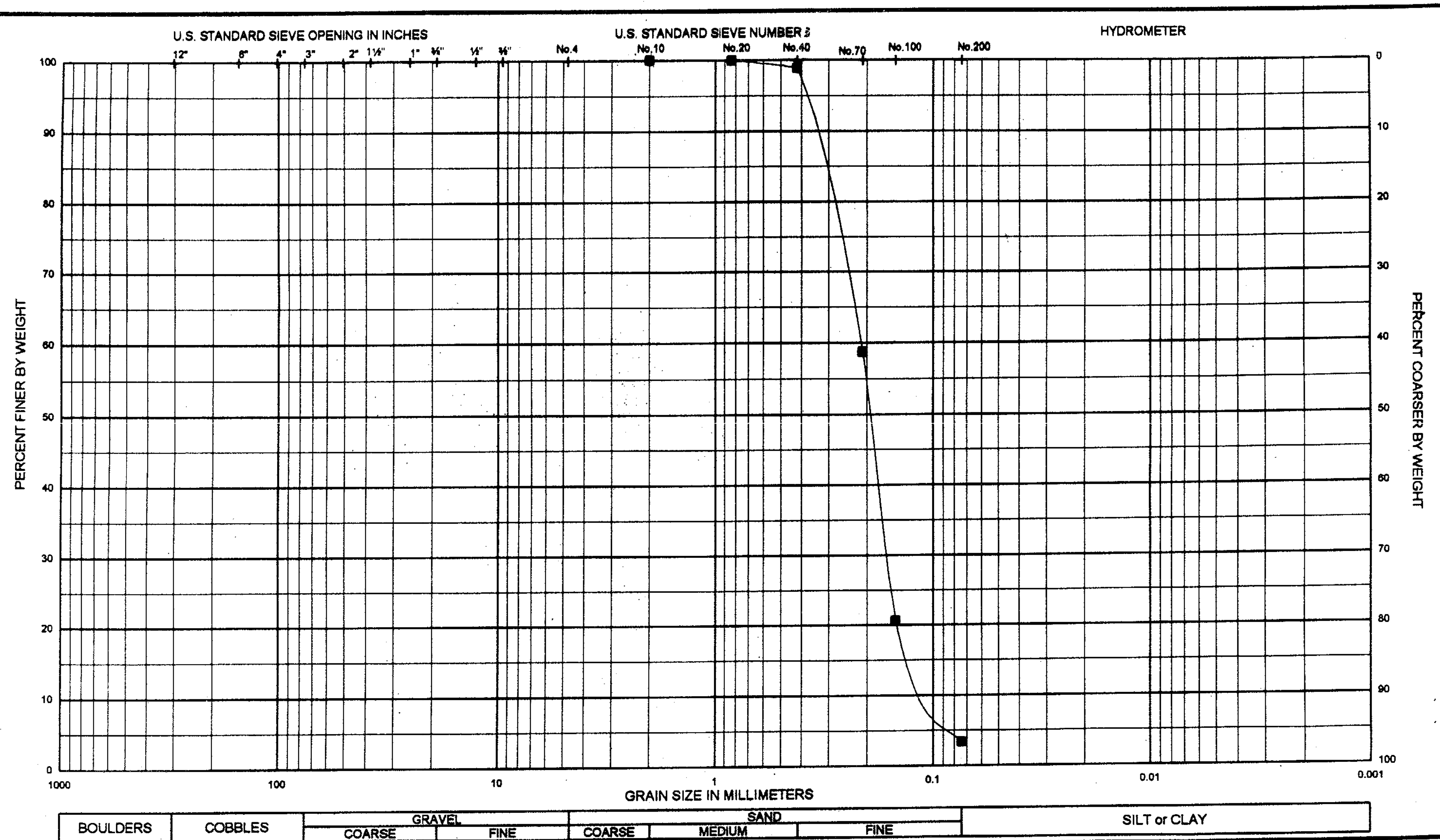
AREA: Somerset County, MD

Boring No.: NW-3

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-4.0	Poorly graded sand $C_u = 1.70$ $C_c = 1.01$ (SP)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

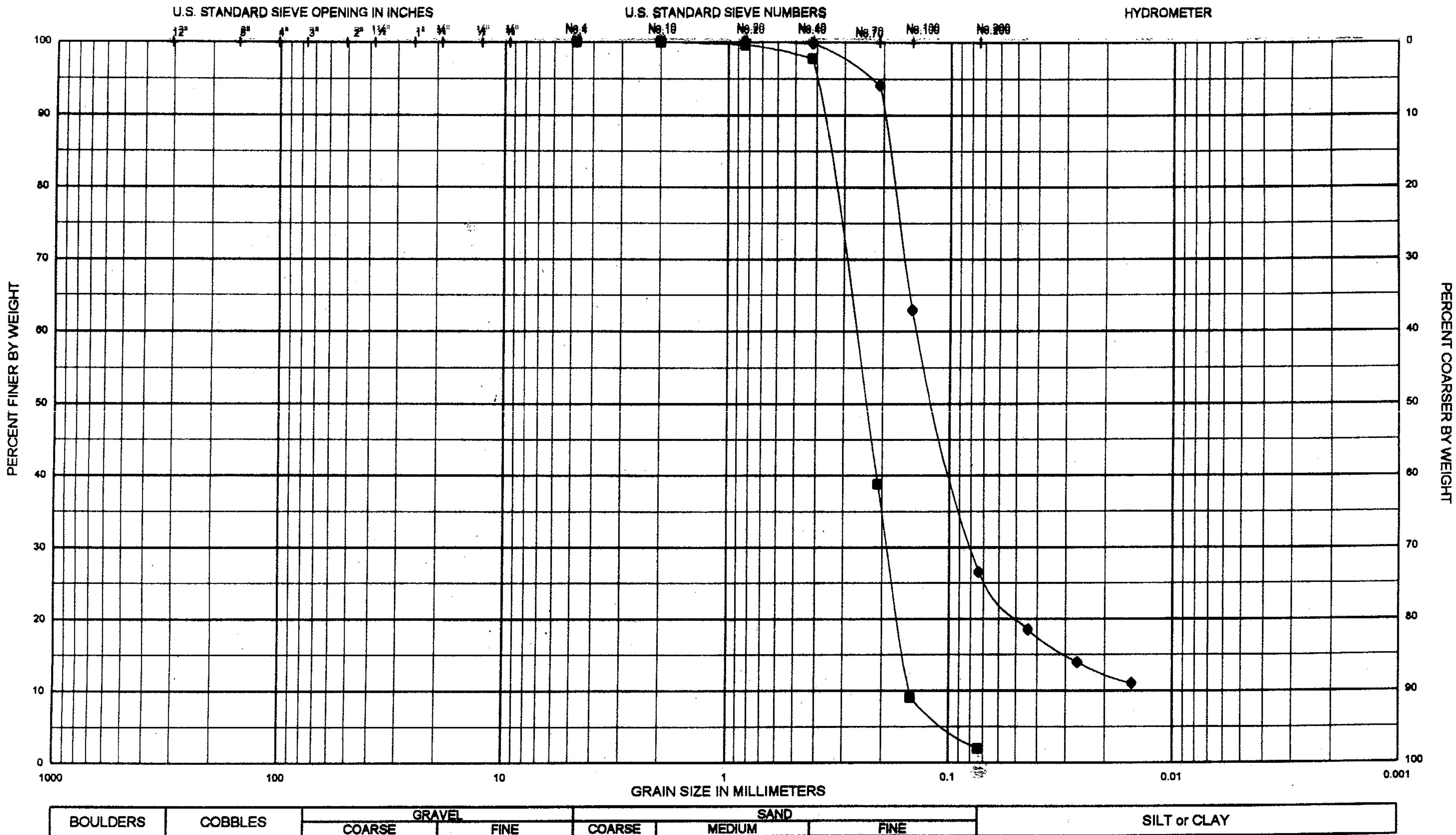
AREA: Somerset County, MD

Boring No.: NW-1

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
■	Jar-1	0.0-4.0	Poorly graded sand Cu:1.63 Cc: .868 (SP)	———	———	———	———
◆	Jar-2,3	4.0-10.0	Silty sand Cu: 10 Cc: 2.84 (SM)	———	———	———	———

PROJECT: Smith Island Environmental Restoration Borrow Areas

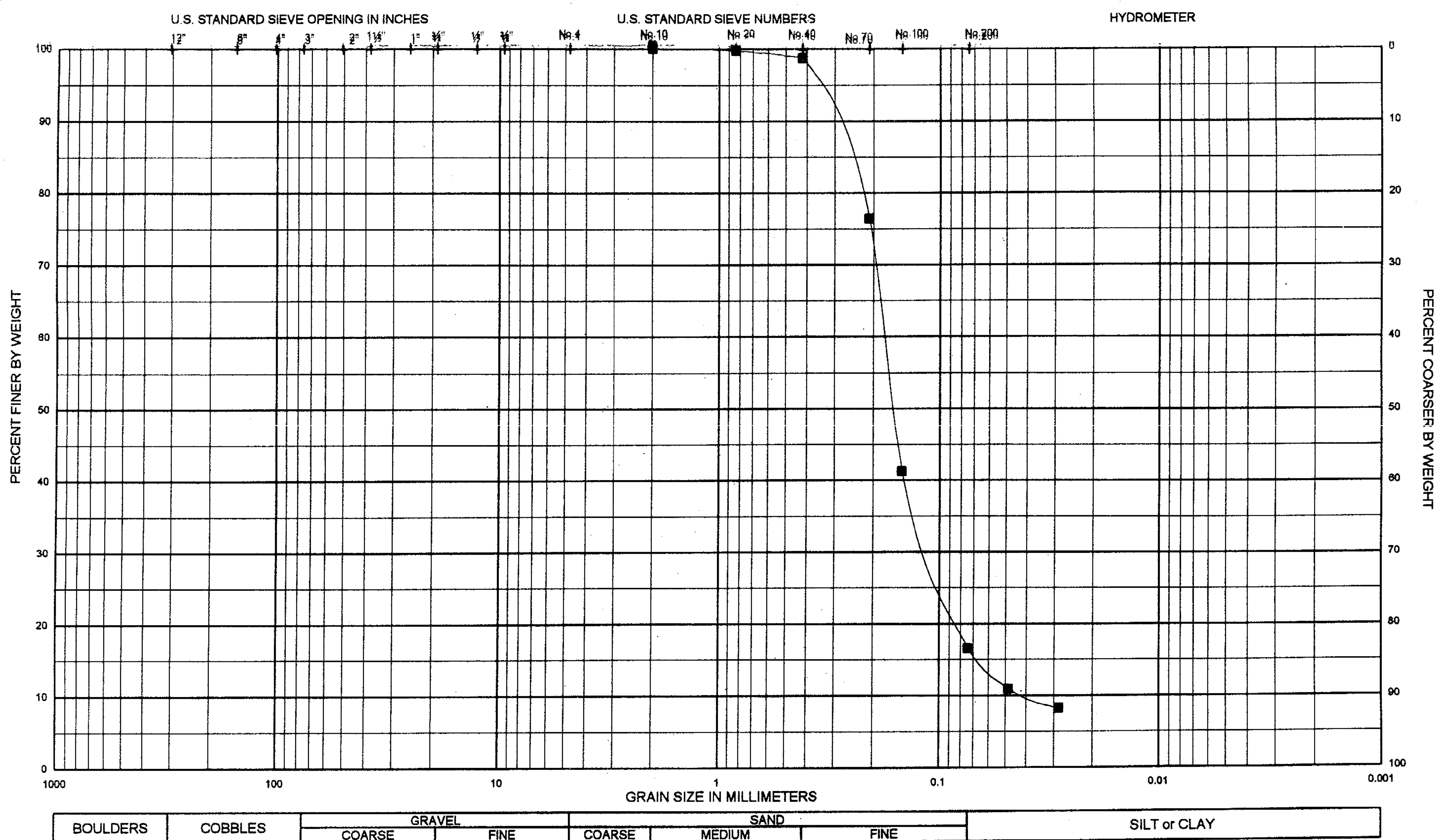
AREA: Somerset County, MD

Boring No.: NW-2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-9.7	Silty sand $C_u = 4$ $C_c = 1.78$ (SM)	—	—	—	—

PROJECT: Smith Island Environmental Restoration Borrow Areas

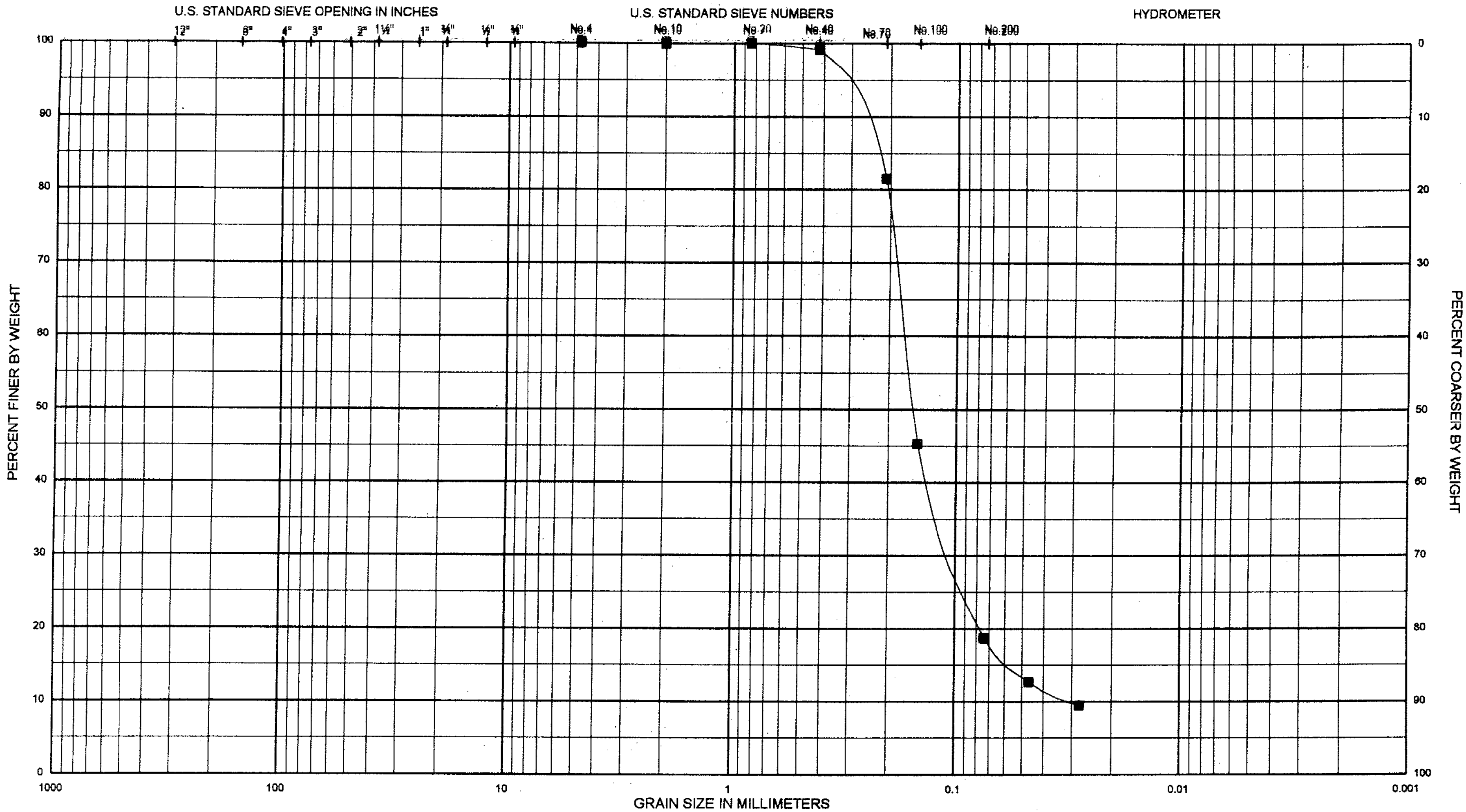
AREA: Somerset County, MD

Boring No.: NW-4

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-8.7	Silty sand C_u = 6 C_c = 2.24 (SM)	—	—	—	—

PROJECT: Smith Island Environmental Restoration Borrow Areas

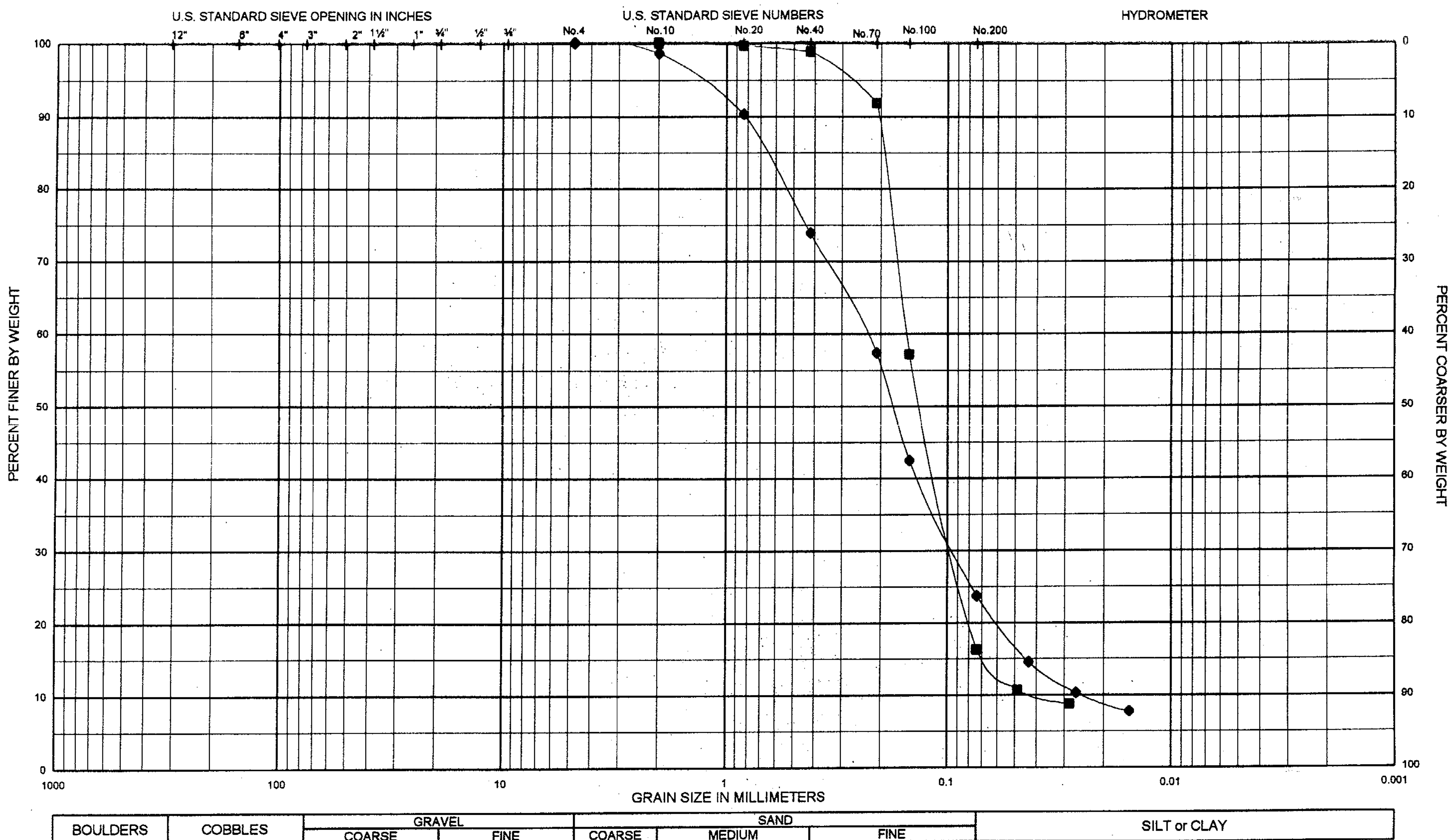
AREA: Somerset County, MD

Boring No.: NW-5

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
■	Jar-1	0.0-5.0	Silty sand $c_u = 3.78$ $c_c = 1.31$ (SM)	—	—	—	—
◆	Jar-2	5.0-9.0	Silty sand $c_u = 8.21$ $c_c = 1.55$ (SM)	—	—	—	—

PROJECT: Smith Island Environmental Restoration Borrow Areas

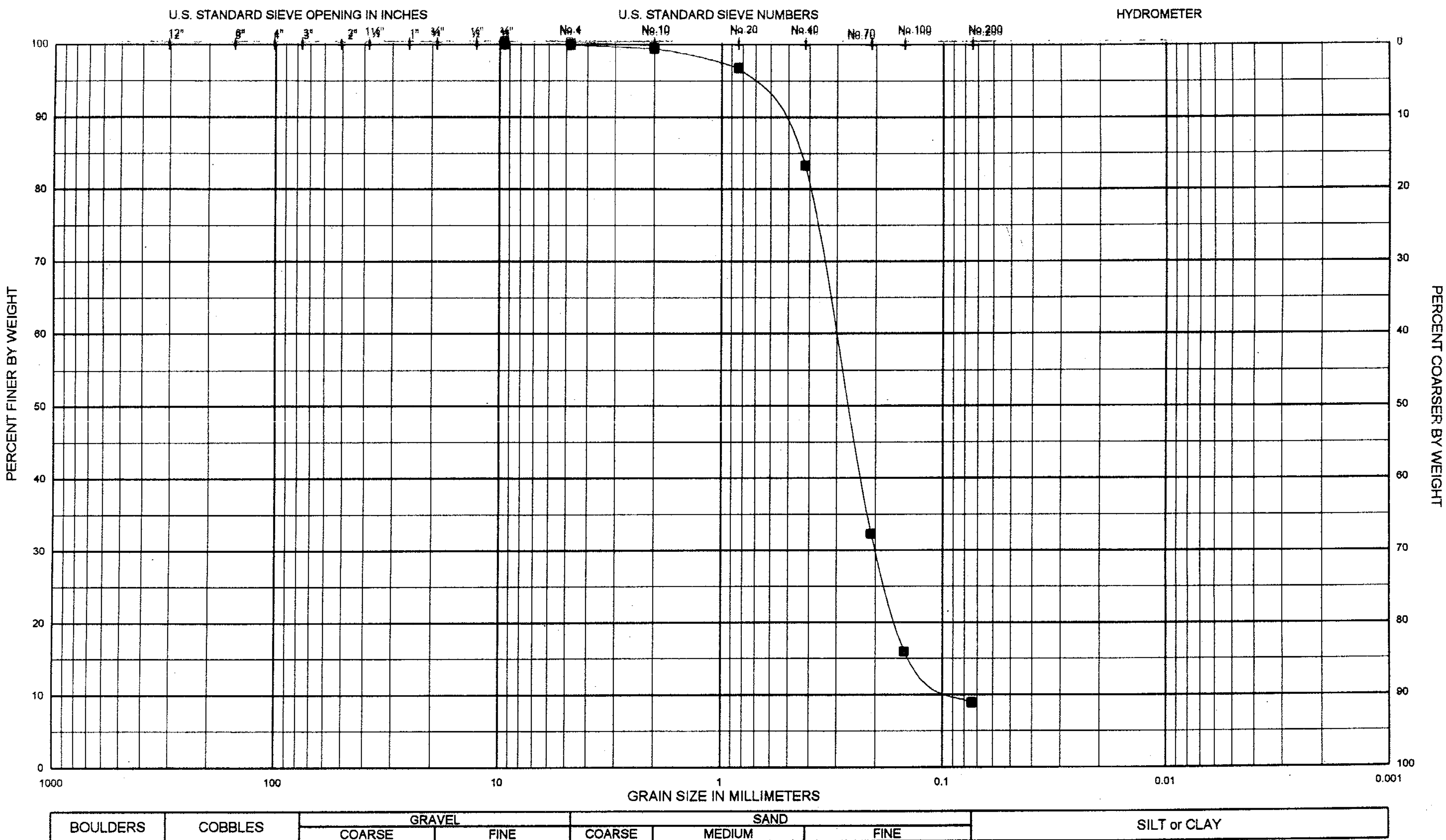
AREA: Somerset County, MD

Boring No.: NW-6

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-4.7	Poorly graded sand with silt $C_u = 3$ $C_c = 1.33$ (SP-SM)	———	———	———	———

PROJECT: Smith Island Environmental Restoration Borrow Areas

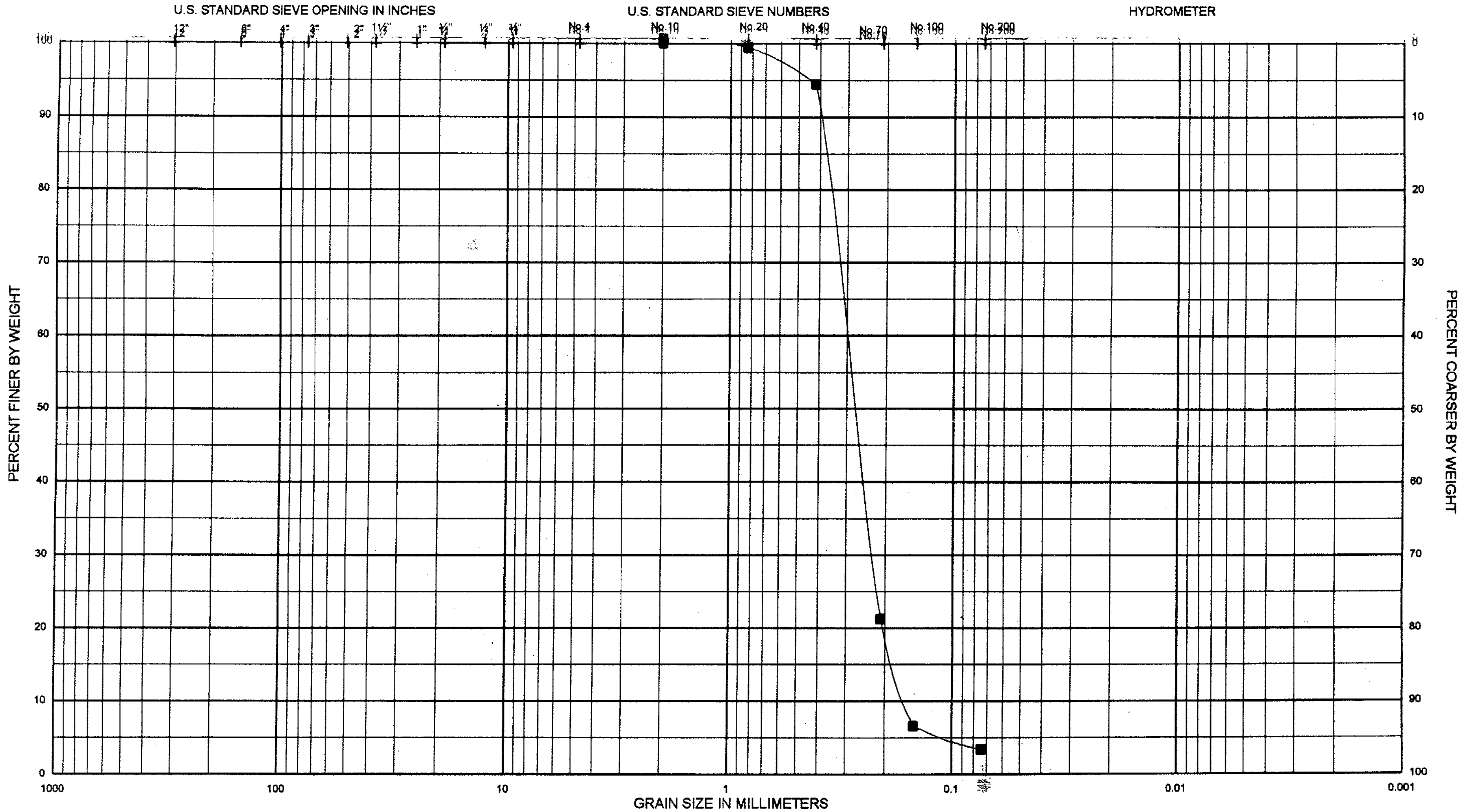
AREA: Somerset County, MD

Boring No.: NW-7

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Poorly graded sand C_u=1.76 C_c= 1.04 (SP)	—	—	—	—

PROJECT: Smith Island Environmental Restoration Borrow Areas

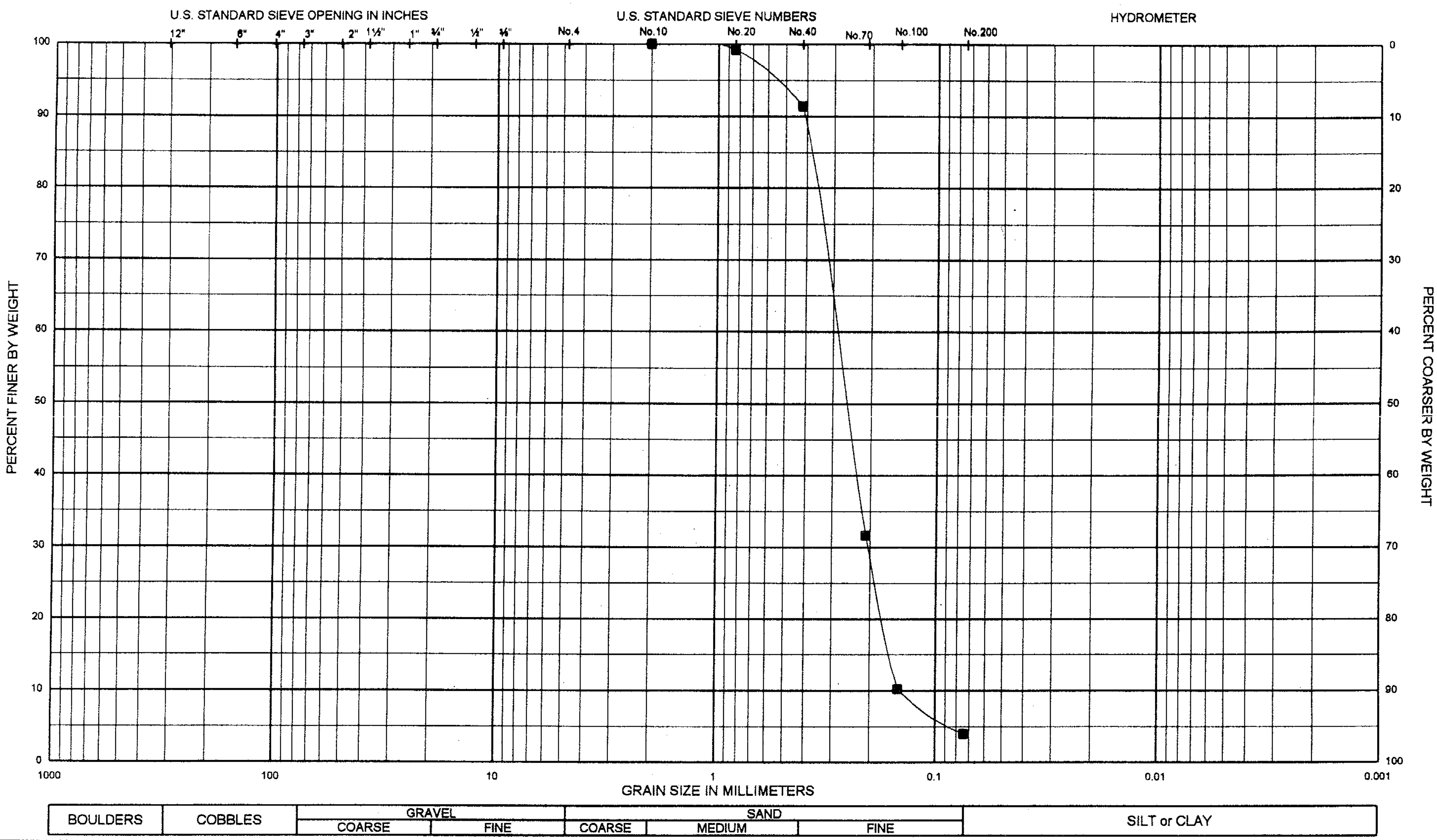
AREA: Somerset County, MD

Boring No.: NW-8

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-9.4	Poorly graded sand $C_u = 1.81$ $C_c = .86$ (SP)	———	———	———	———

PROJECT: Smith Island Environmental Restoration Borrow Areas

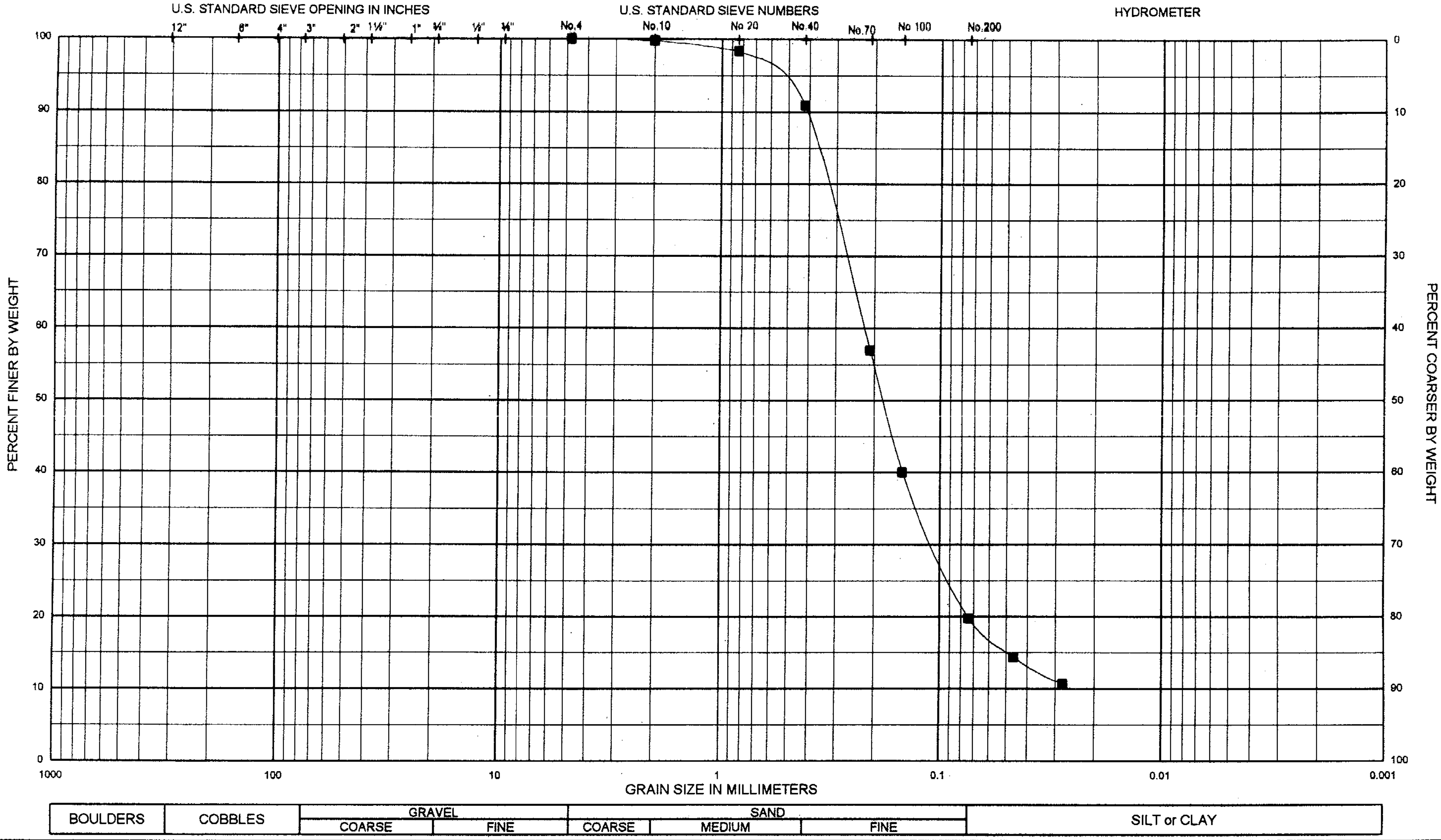
AREA: Somerset County, MD

Boring No.: NW-9

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Silty sand $C_u = 8.8$ $C_c = 2.2$ (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

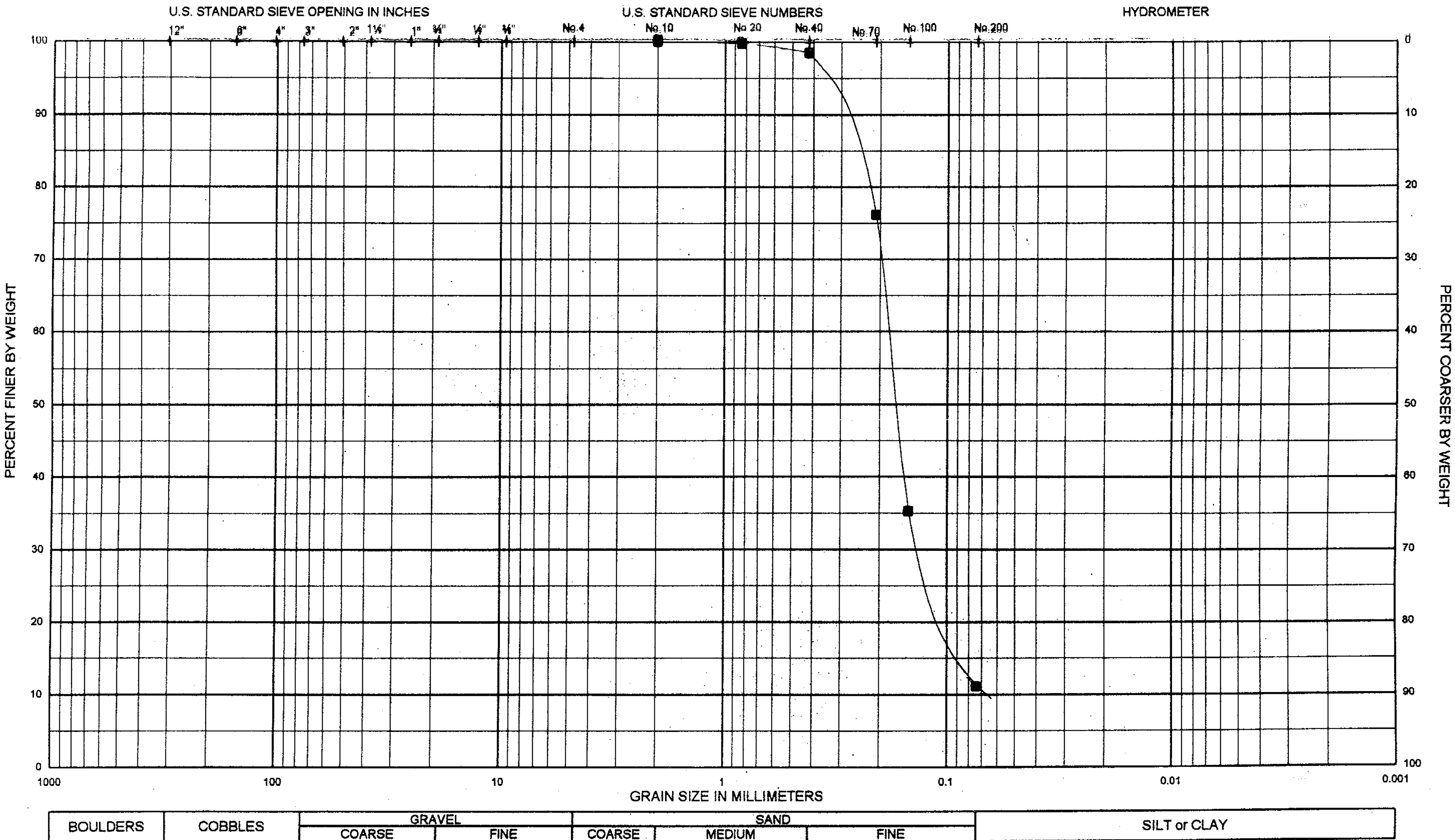
AREA: Somerset County, MD

Boring No.: NW-10

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-8.6	Poorly graded sand with silt $C_u = 2.88$ $C_c = 1.56$ (SP-SM)	———	———	———	———

PROJECT: Smith Island Environmental Restoration Borrow Areas

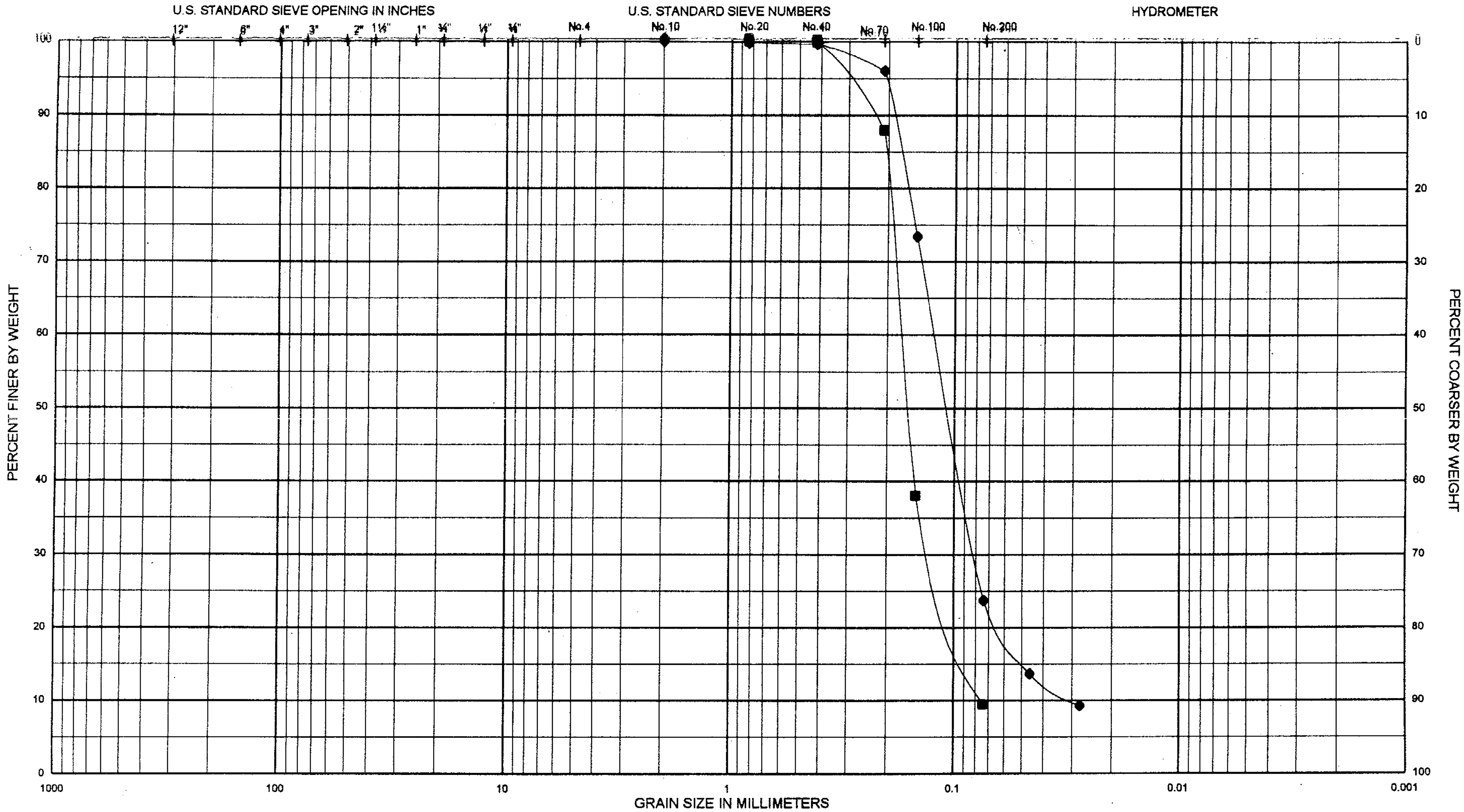
AREA: Somerset County, MD

Boring No.: NW-13

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
―■―	Jar-1	0.0-5.0	Poorly graded sand with silt $C_u = 2.27$ $C_c = 1.54$ (SP-SM)	――	――	――	――
―◆―	Jar-2	5.0-10.0	Silty sand $C_u = 4.06$ $C_c = 1.66$ (SM)	――	――	――	――

PROJECT: Smith Island Environmental Restoration Borrow Areas

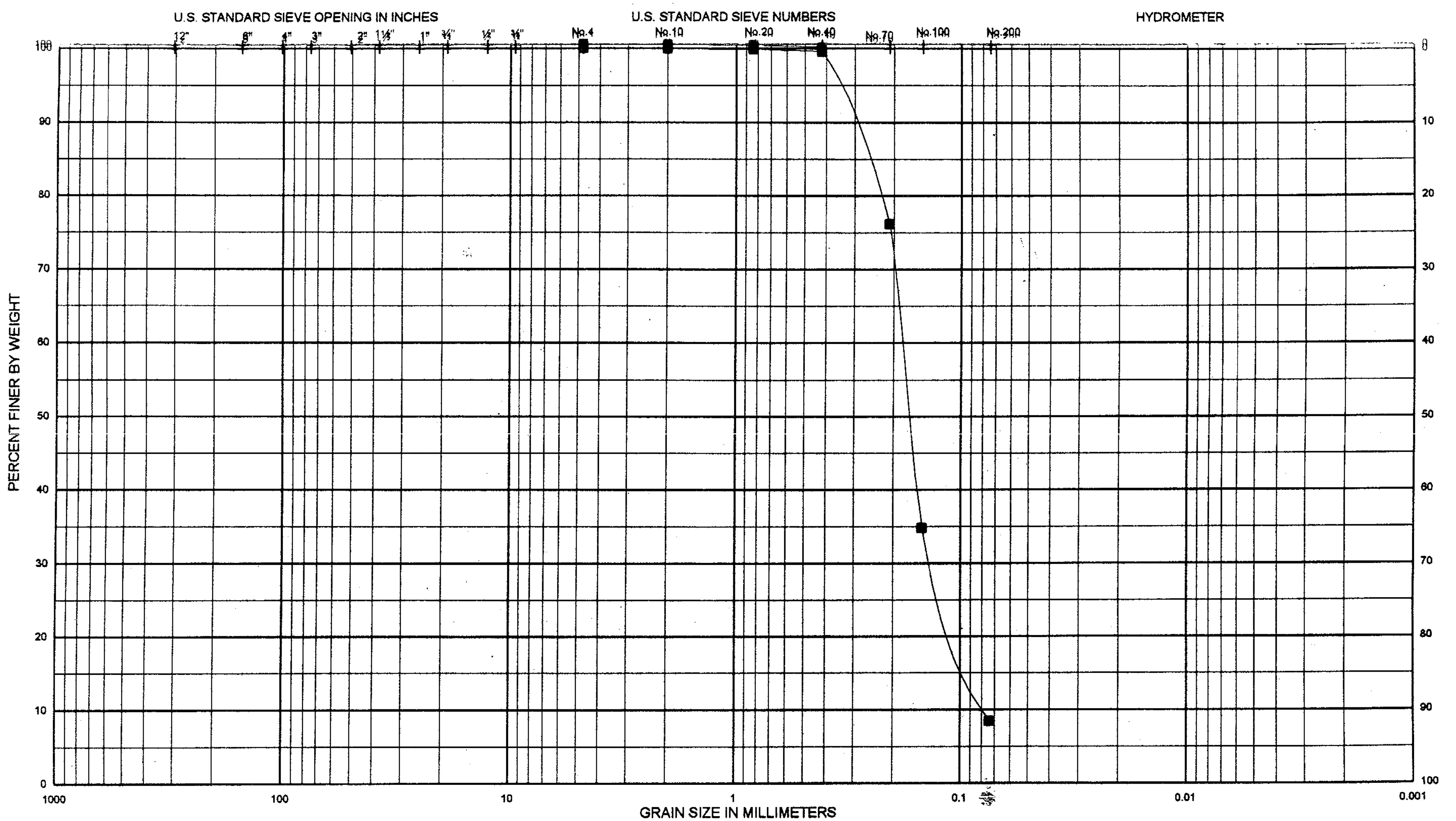
AREA: Somerset County, MD

Boring No.: SP-3

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-10.0	Poorly graded sand with silt $C_u=2.25$ $C_c=1.36$ (SP-SM)	———	———	———	———

PROJECT: Smith Island Environmental Restoration Borrow Areas

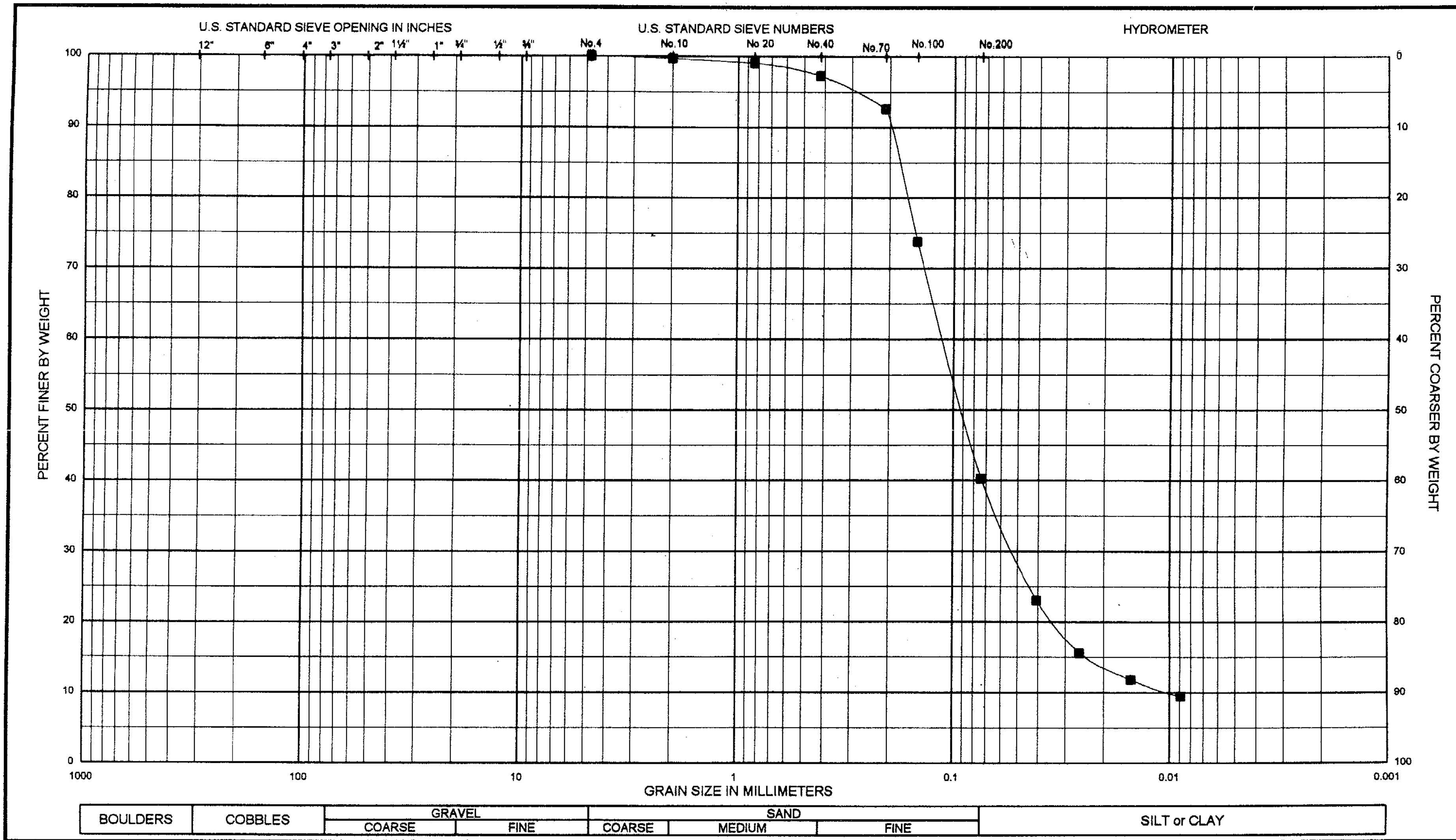
AREA: Somerset County, MD

Boring No.: SP-4

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-10.0	Silty sand $C_u = 12$ $C_c = 2.52$ (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

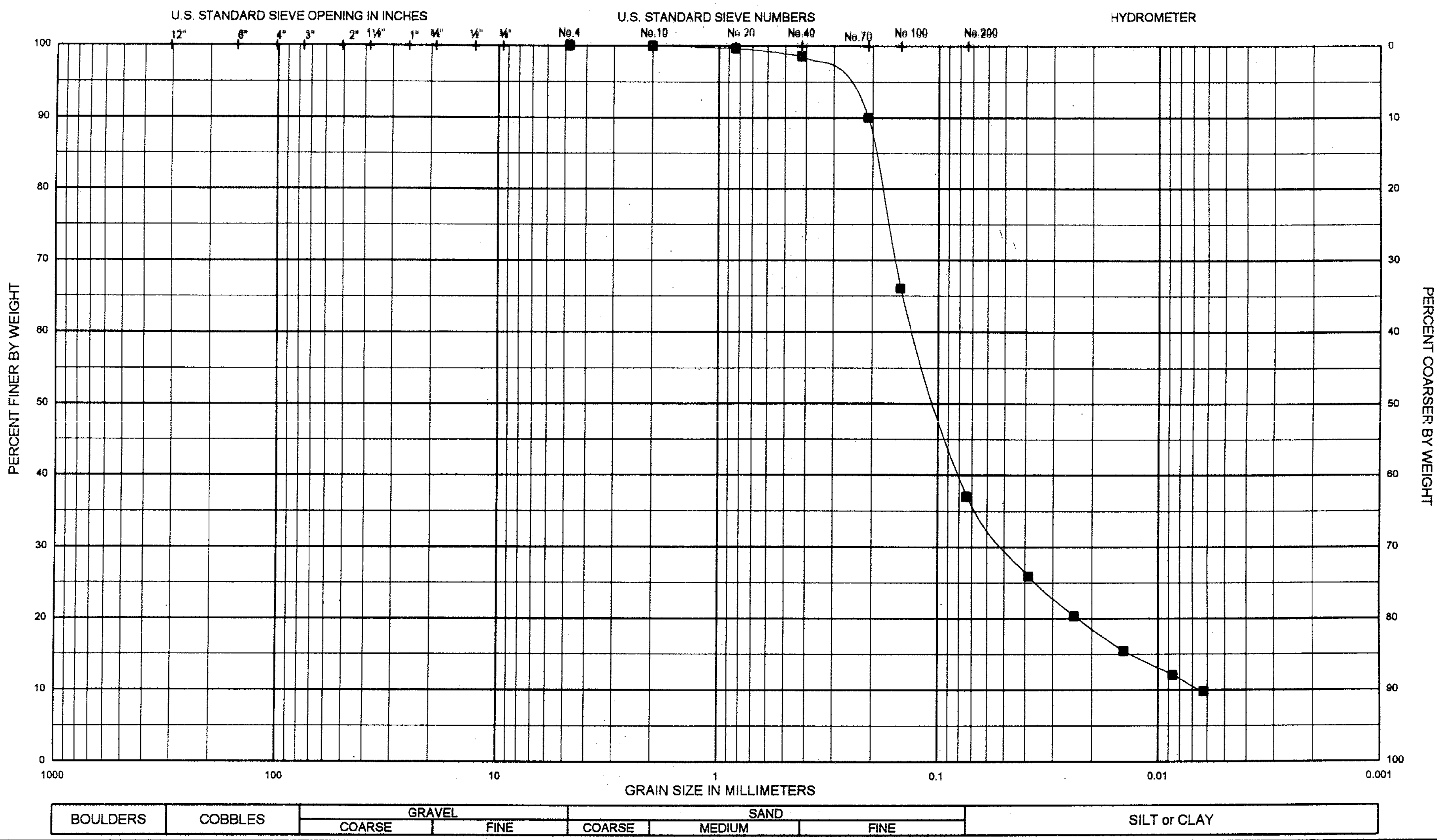
AREA: Somerset County, MD

Boring No.: SP-5

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-9.5	Silty sand $C_u = 21.54$ $C_c = 2.97$ (SM)	——	——	——	——

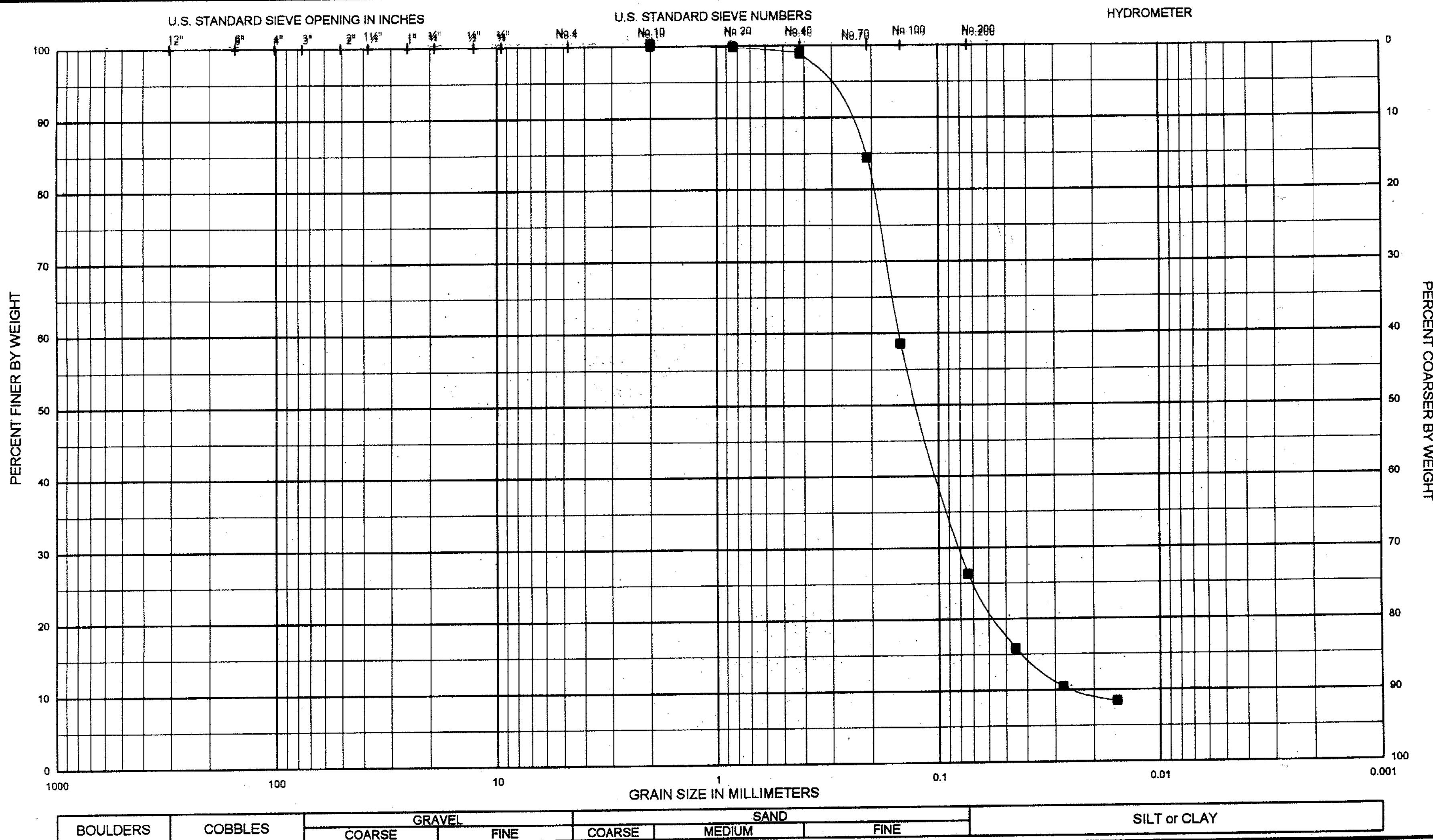
PROJECT: Smith Island Environmental Restoration Borrow Areas

AREA: Somerset County, MD

Boring No.: SP-6

DATE: Jan 1999

ENG FORM 2087 **GRADATION CURVES**



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1,2	0.0-10.0	Silty sand $C_u = 5.93$ $C_c = 1.56$ (SM)	———	———	———	———

PROJECT: Smith Island Environmental Restoration Borrow Areas

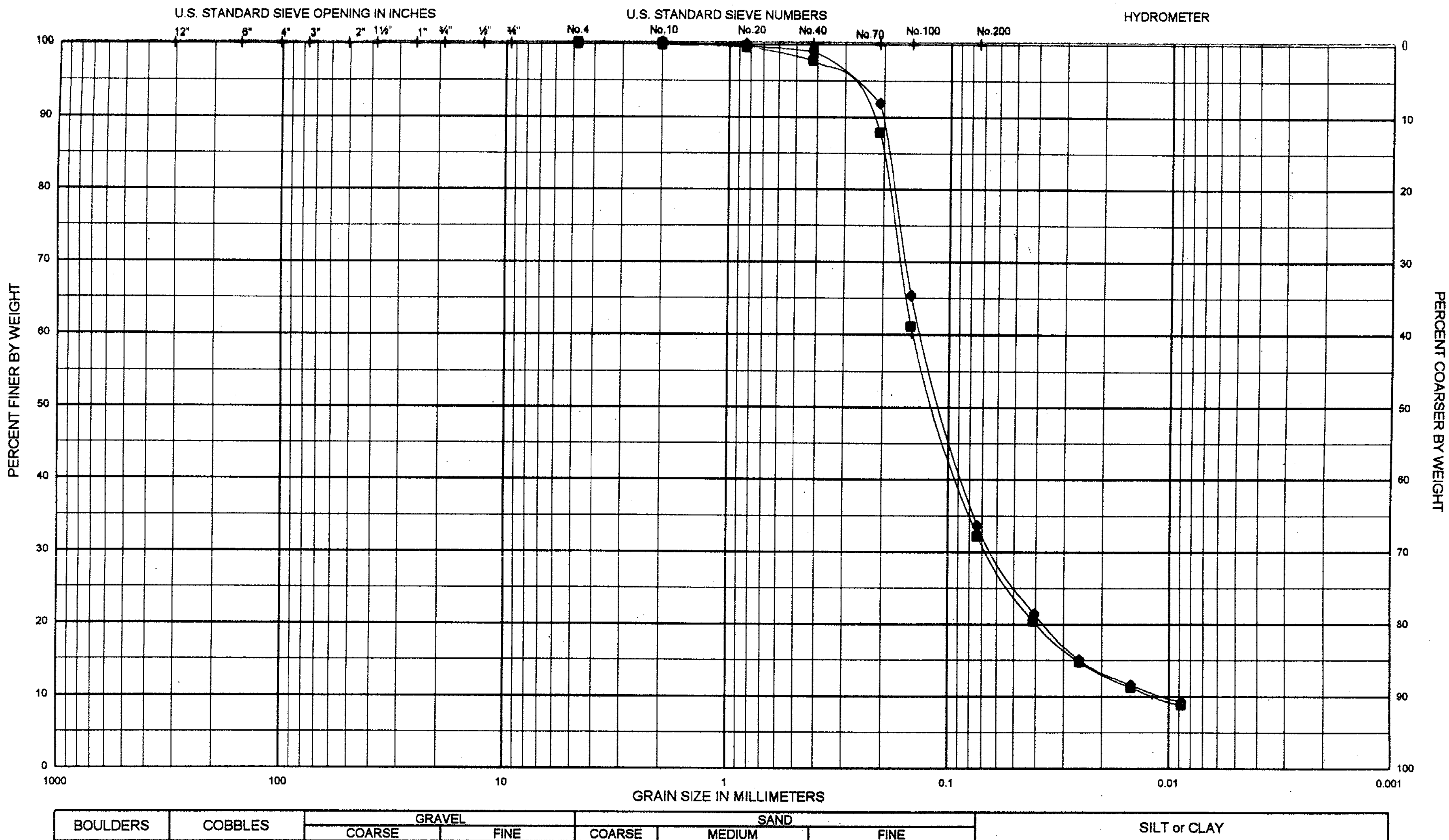
AREA: Somerset County, MD

Boring No.: SP-7

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Silty sand $C_u = 13.33$ $C_c = 2.41$ (SM)	——	——	——	——
—◆—	Jar-2	5.0-10.0	Silty sand $C_u = 12.73$ $C_c = 2.74$ (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

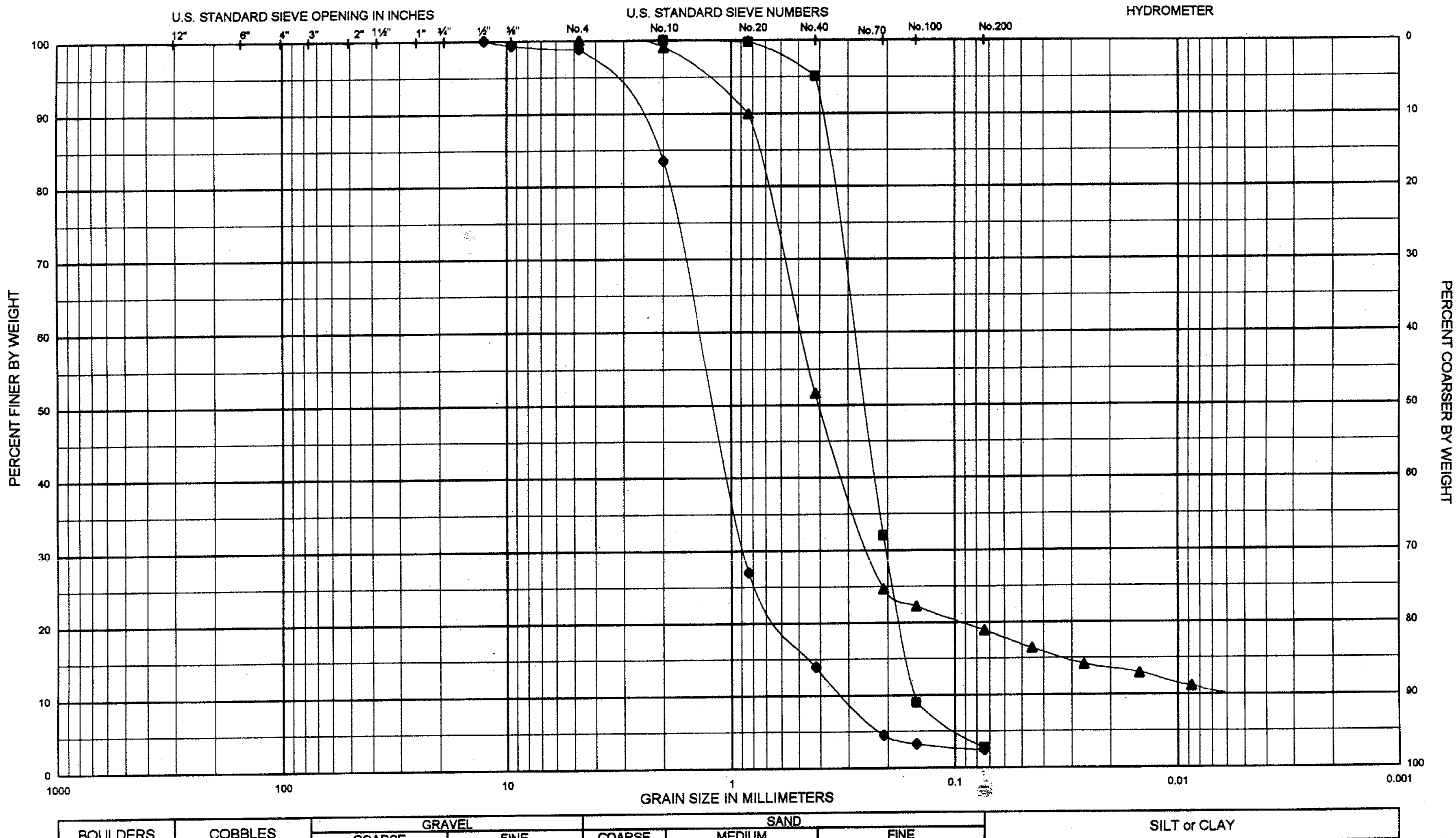
AREA: Somerset County, MD

Boring No.: SP-8

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Poorly graded sand $C_u = 1.75$ $C_c = .98$ (SP)	——	——	——	——
—◆—	Jar-2	5.0-7.5	Poorly graded sand (tr. gravel) $C_u = 4.24$ $C_c = 1.75$ (SP)	——	——	——	——
—▲—	Jar-3	7.5-10.0	Clayey sand $C_u = 7.54$ $C_c = 2.12$ (SC)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

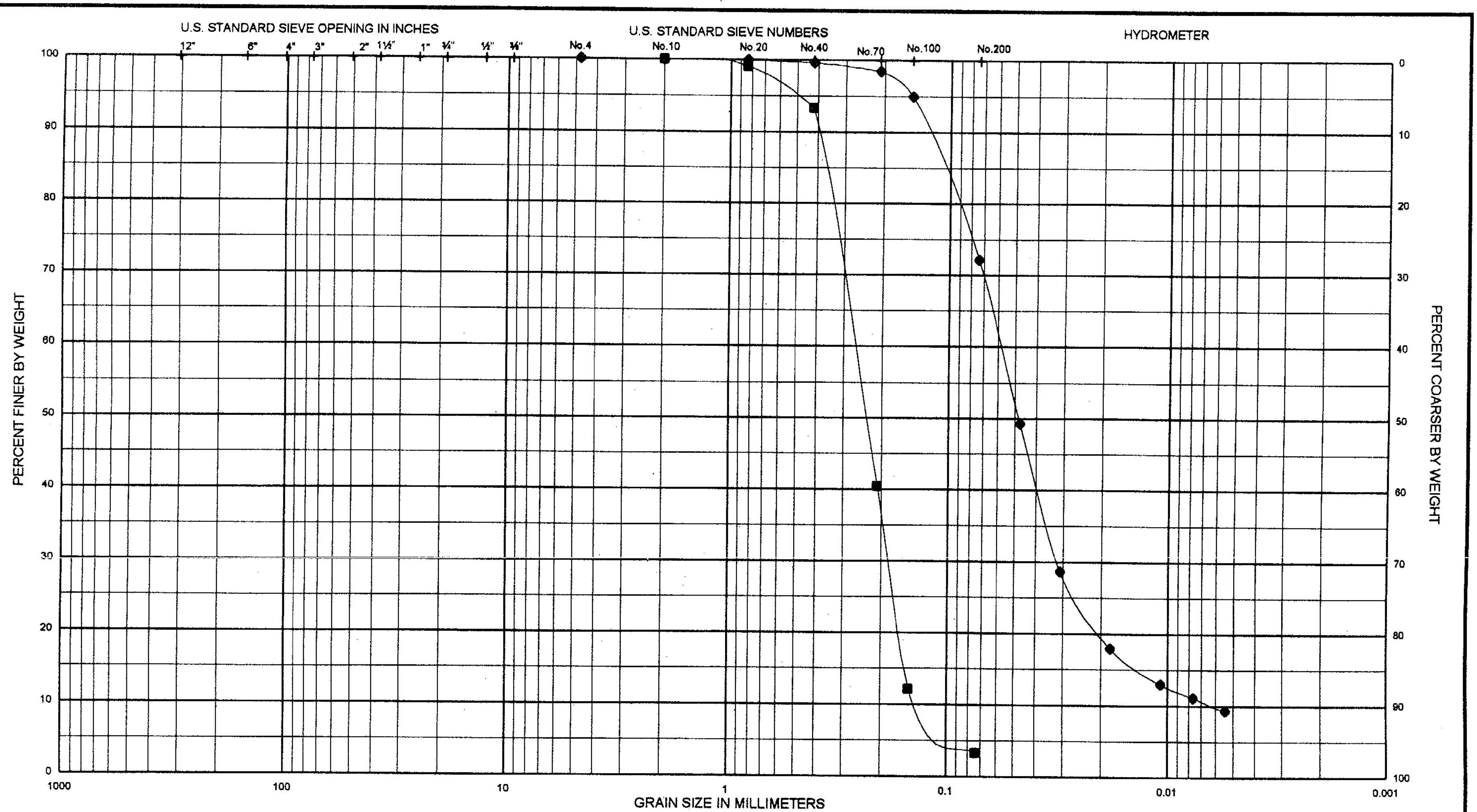
AREA: Somerset County, MD

Boring No.: SP-11

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



BOULDERS	COBBLES	GRAVEL		SAND			SILT or CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-4.4	Poorly graded sand C_u=1.8 C_c=.8 (SP)	——	——	——	——
—◆—	Jar-2	4.4-5.0	Silt with sand C_u=10.46 C_c=3.41 (ML)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

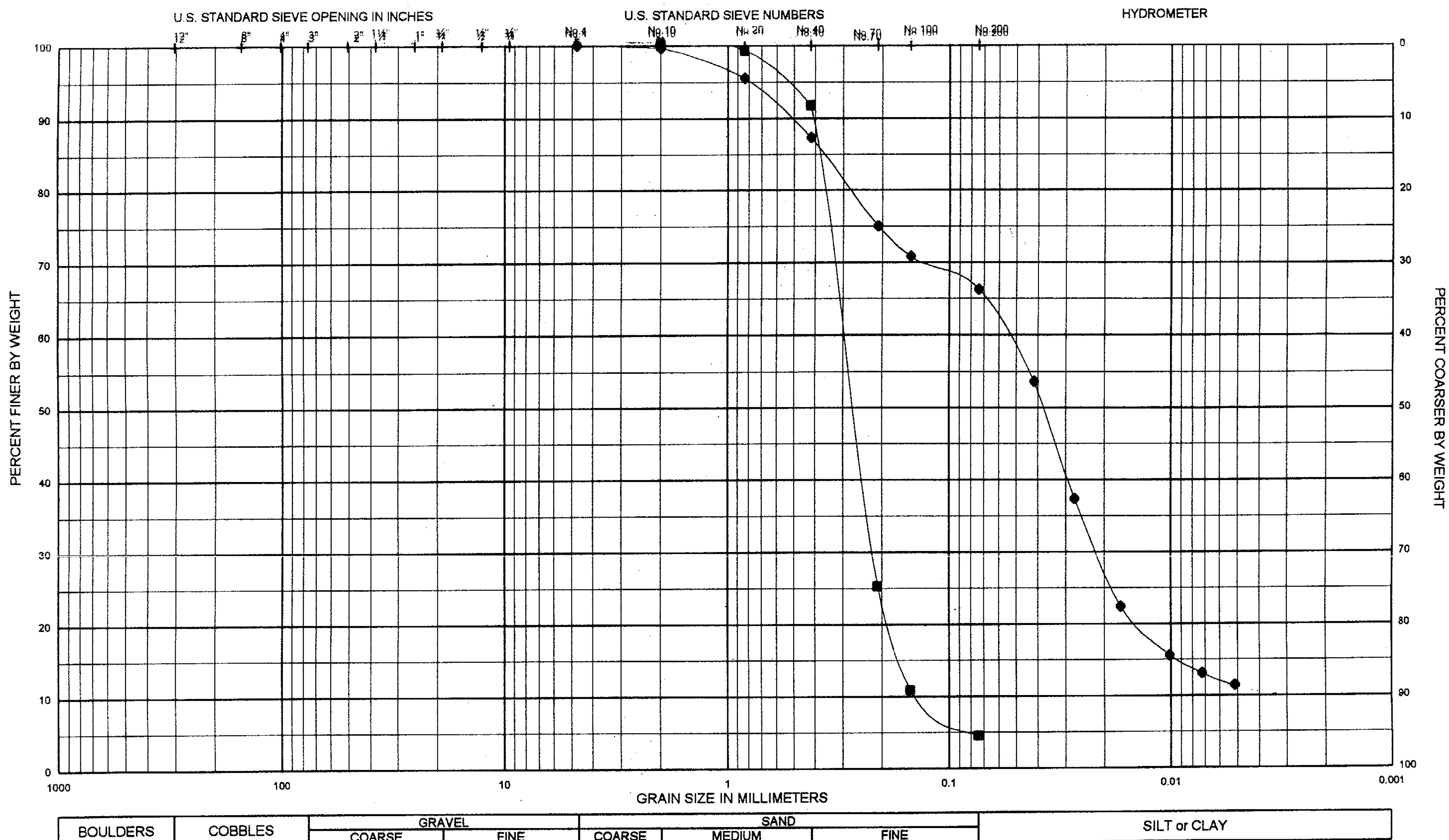
AREA: Somerset County, MD

Boring No.: SP-12

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-2.5	Poorly graded sand $C_u = 2$ $C_c = 1.08$ (SP)	——	——	——	——
—◆—	Jar-2	2.5-5.0	Sandy silt $C_u = 15.71$ $C_c = 2.51$ (ML)	——	——	——	——

PROJECT: Smith Island Environmental Restoration
Borrow Areas

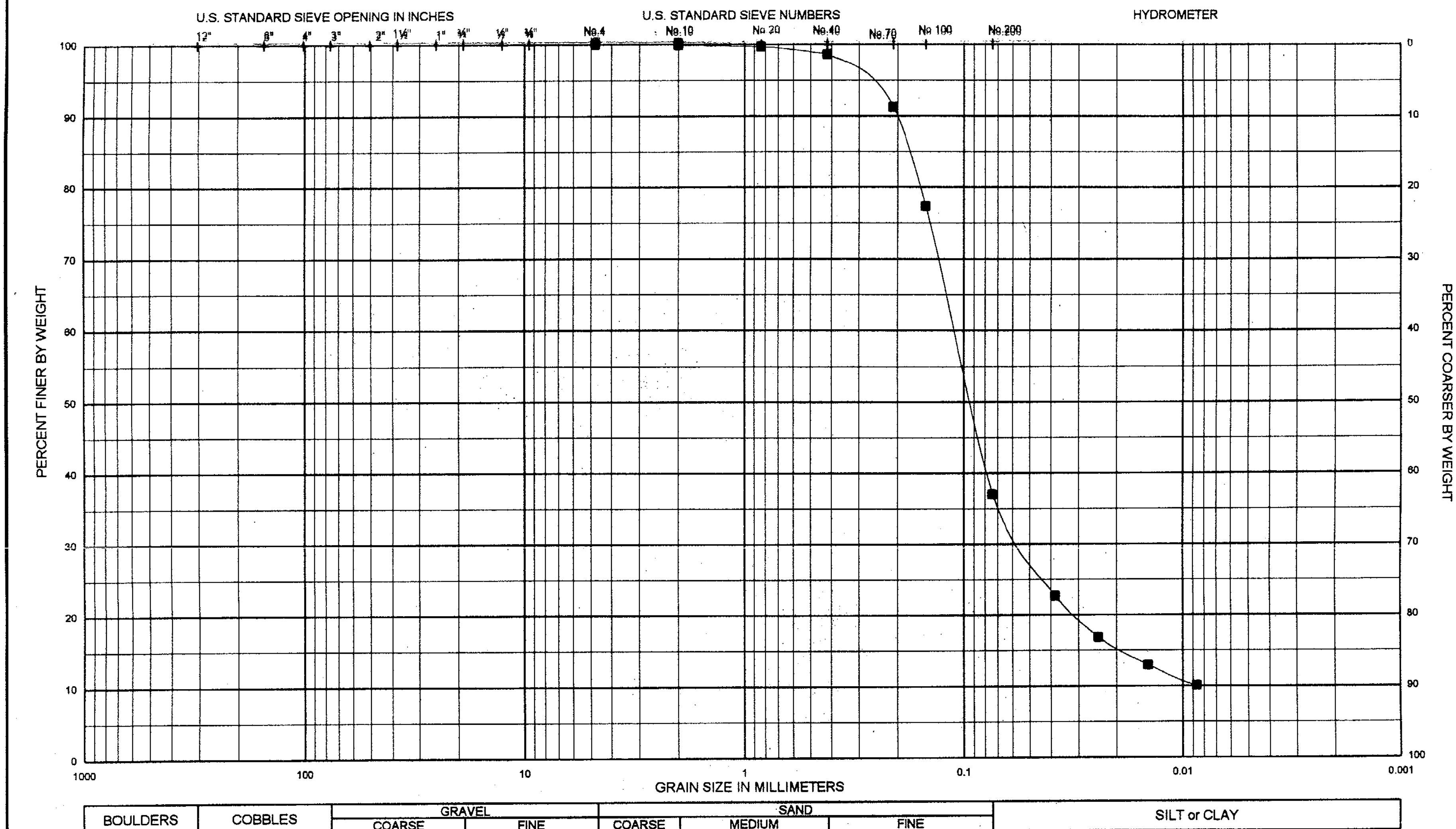
AREA: Somerset County, MD

Boring No.: SP-16

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Silty sand $C_u = 12.5$ $C_c = 3.60$ (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

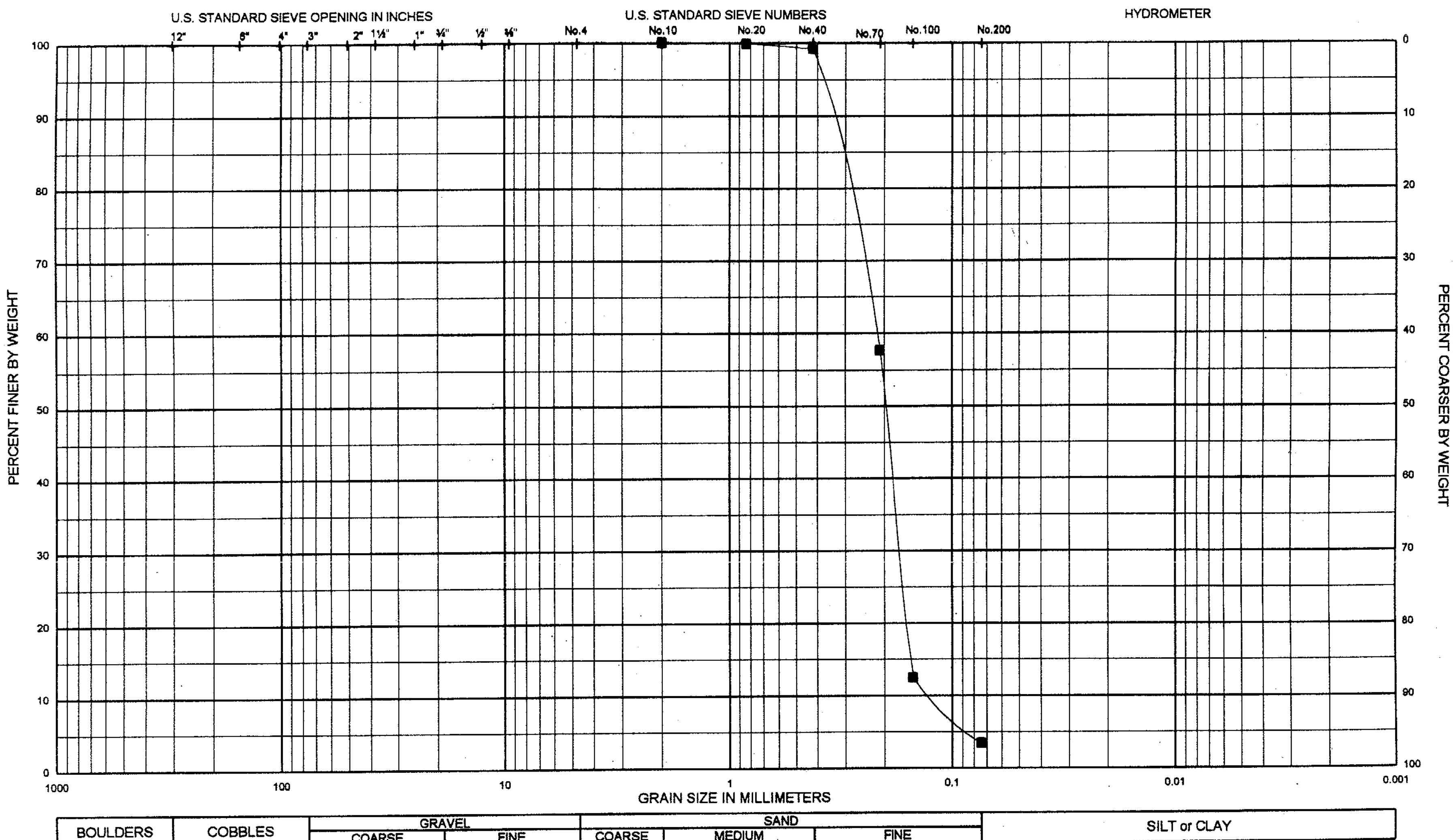
AREA: Somerset County, MD

Boring No.: NB-1

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Poorly graded sand $C_u = 1.5$ $C_c = .98$ (SP)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

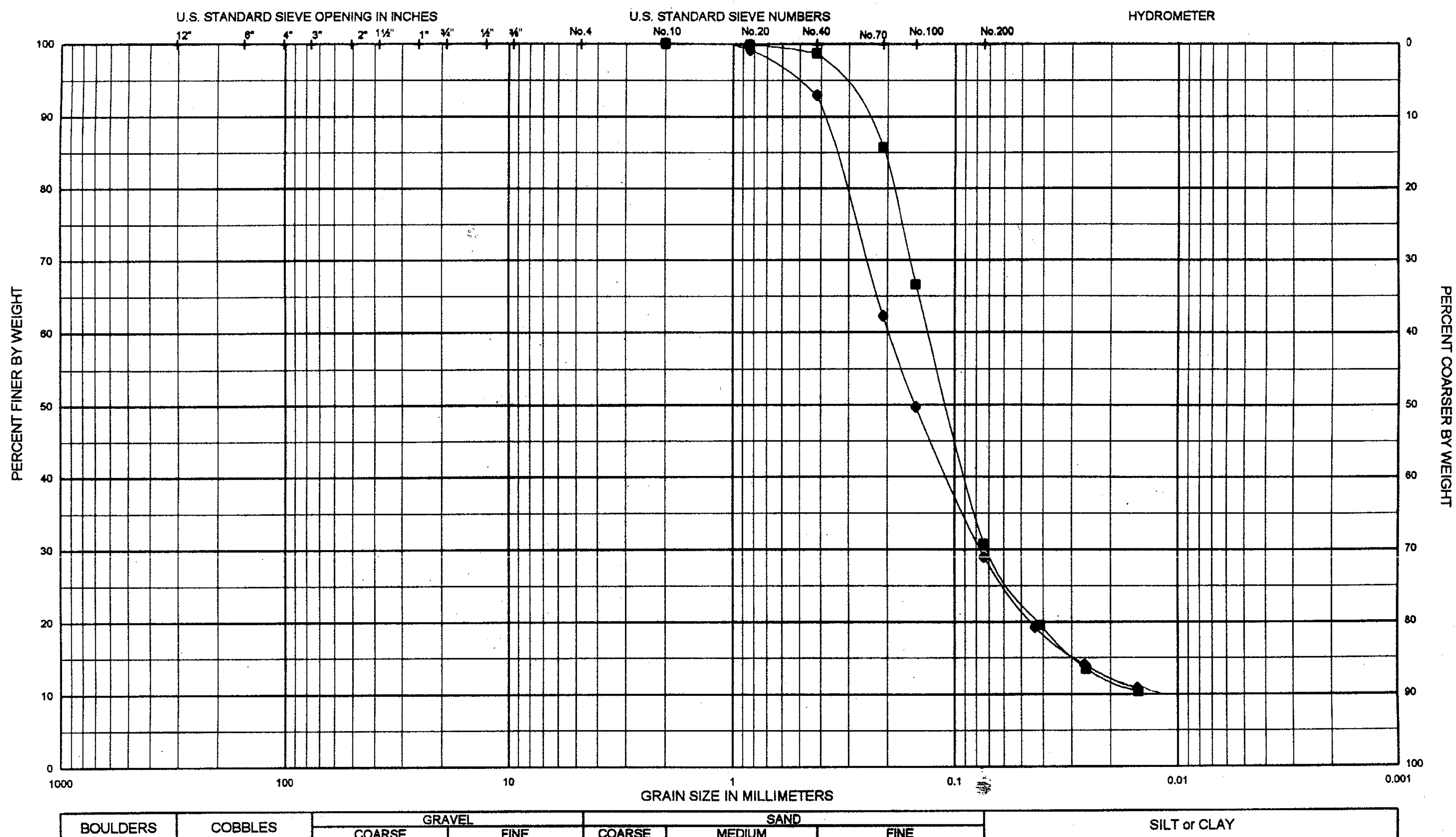
AREA: Somerset County, MD

Boring No.: NB-2

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Silty sand $C_u = 9.33$ $C_c = 2.47$ (SM)	——	——	——	——
—◆—	Jar-2	5.0-8.1	Silty sand $C_u = 16.67$ $C_c = 2.34$ (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

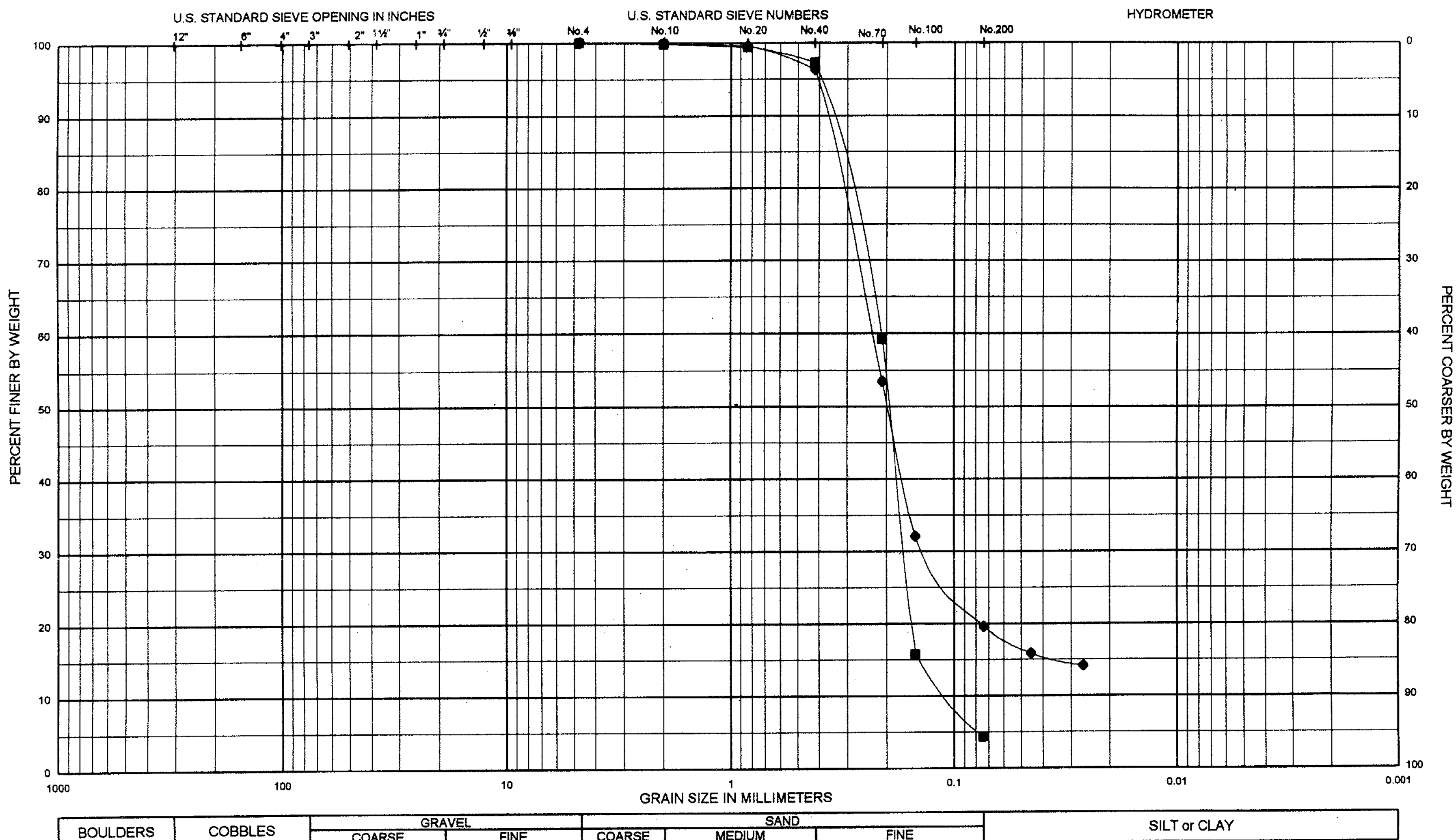
AREA: Somerset County, MD

Boring No.: NB-4

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
■	Jar-1	0.0-0.5	Poorly graded sand $C_u = 1.75$ $C_c = 1.15$ (SP)	—	—	—	—
◆	Jar-2	7.0-7.7	Silty sand $C_u = N/A$ $C_c = N/A$ (SM)	—	—	—	—

PROJECT: Smith Island Environmental Restoration Borrow Areas

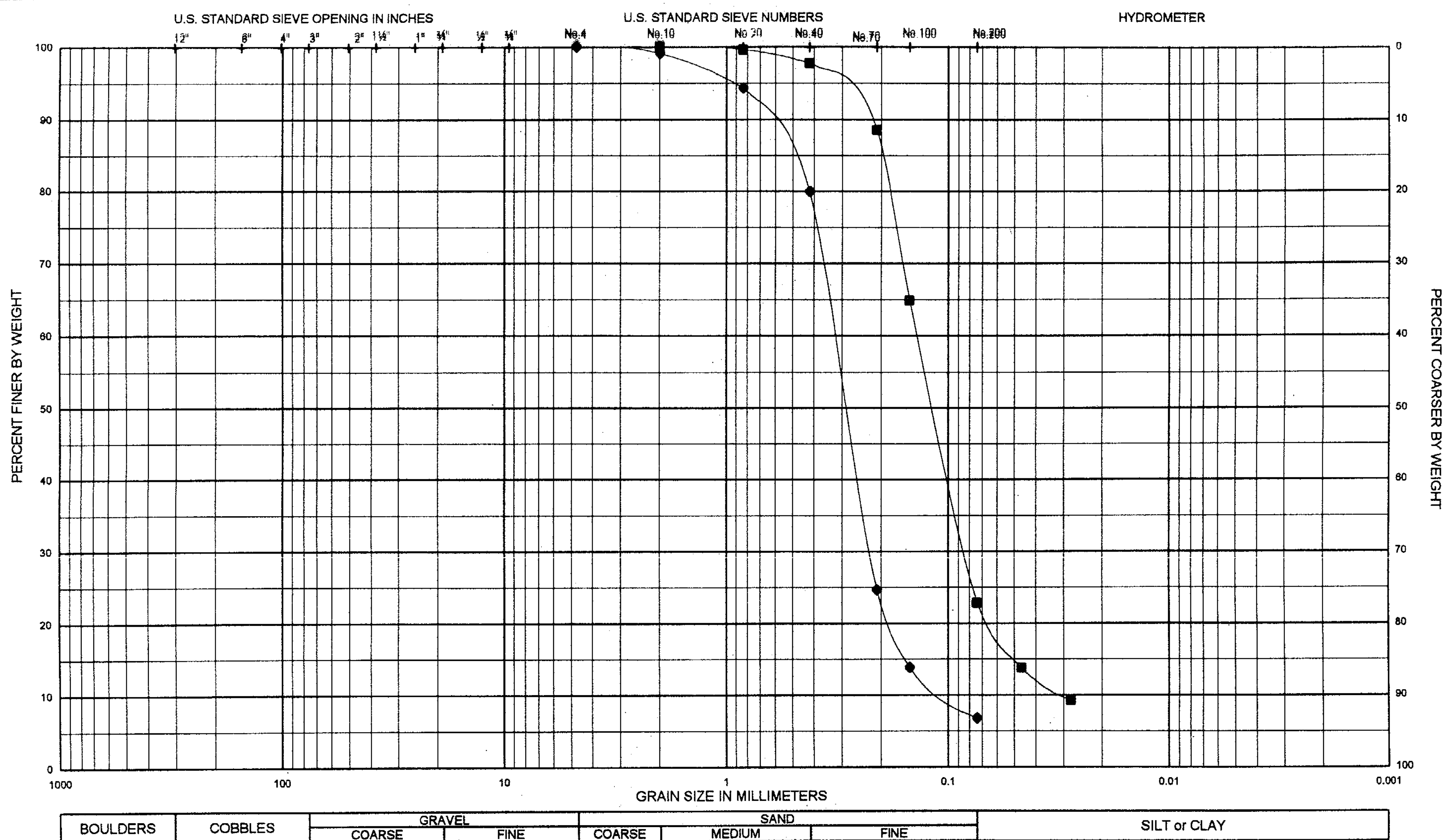
AREA: Somerset County, MD

Boring No.: NB-5

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
■	Jar-1	0.0-4.3	Silty sand $C_u = 4.69$ $C_c = 1.51$ (SM)	—	—	—	—
◆	Jar-2,3	4.3-9.0	Poorly graded sand with silt $C_u = 2.67$ $C_c = 1.38$ (SP-SM)	—	—	—	—

PROJECT: Smith Island Environmental Restoration Borrow Areas

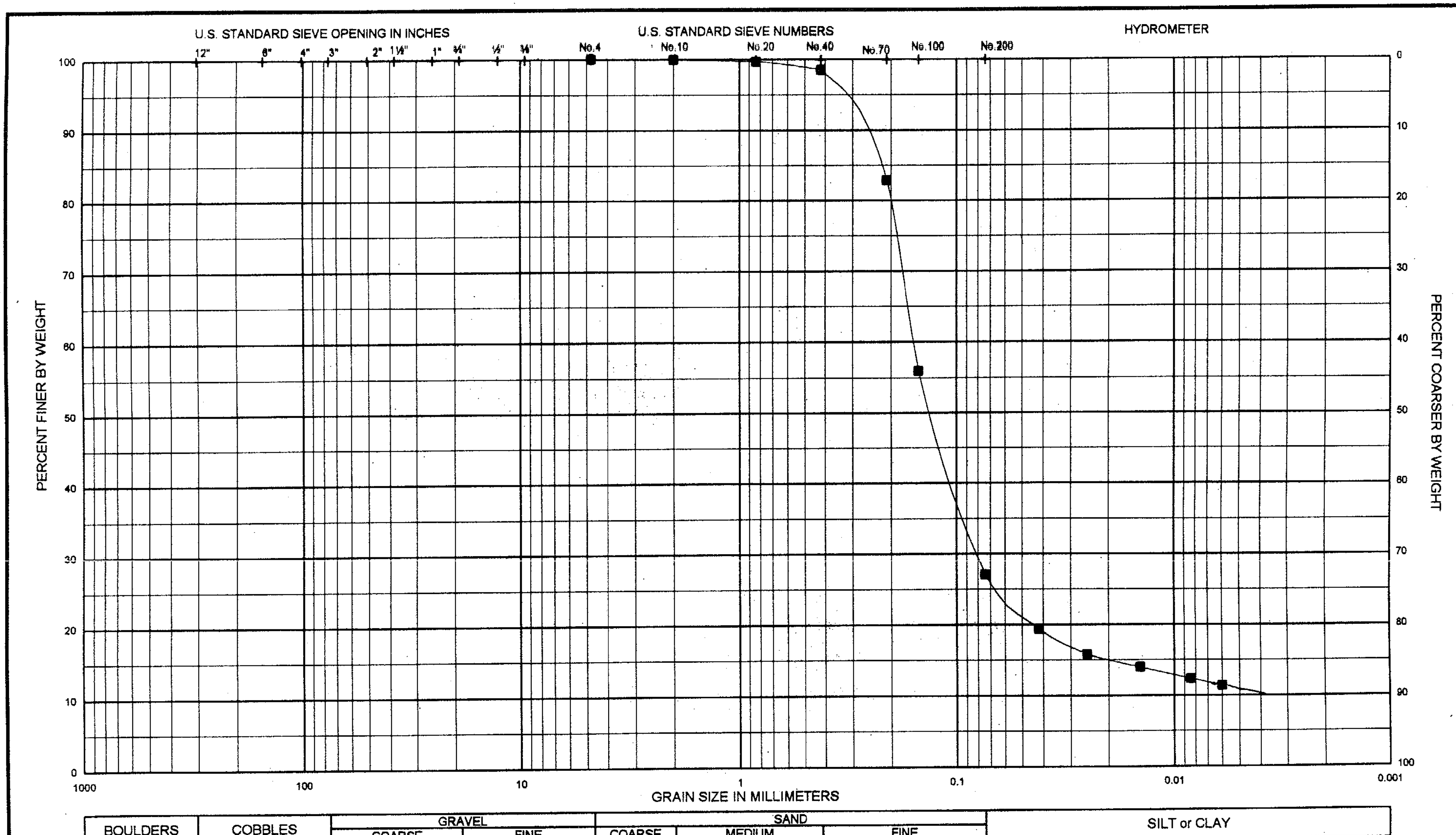
AREA: Somerset County, MD

Boring No.: NB-7

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	4.2-5.0	Silty sand $C_u = 42.5$ $C_c = 9.65$ (SM)	——	——	——	——

PROJECT: Smith Island Environmental Restoration Borrow Areas

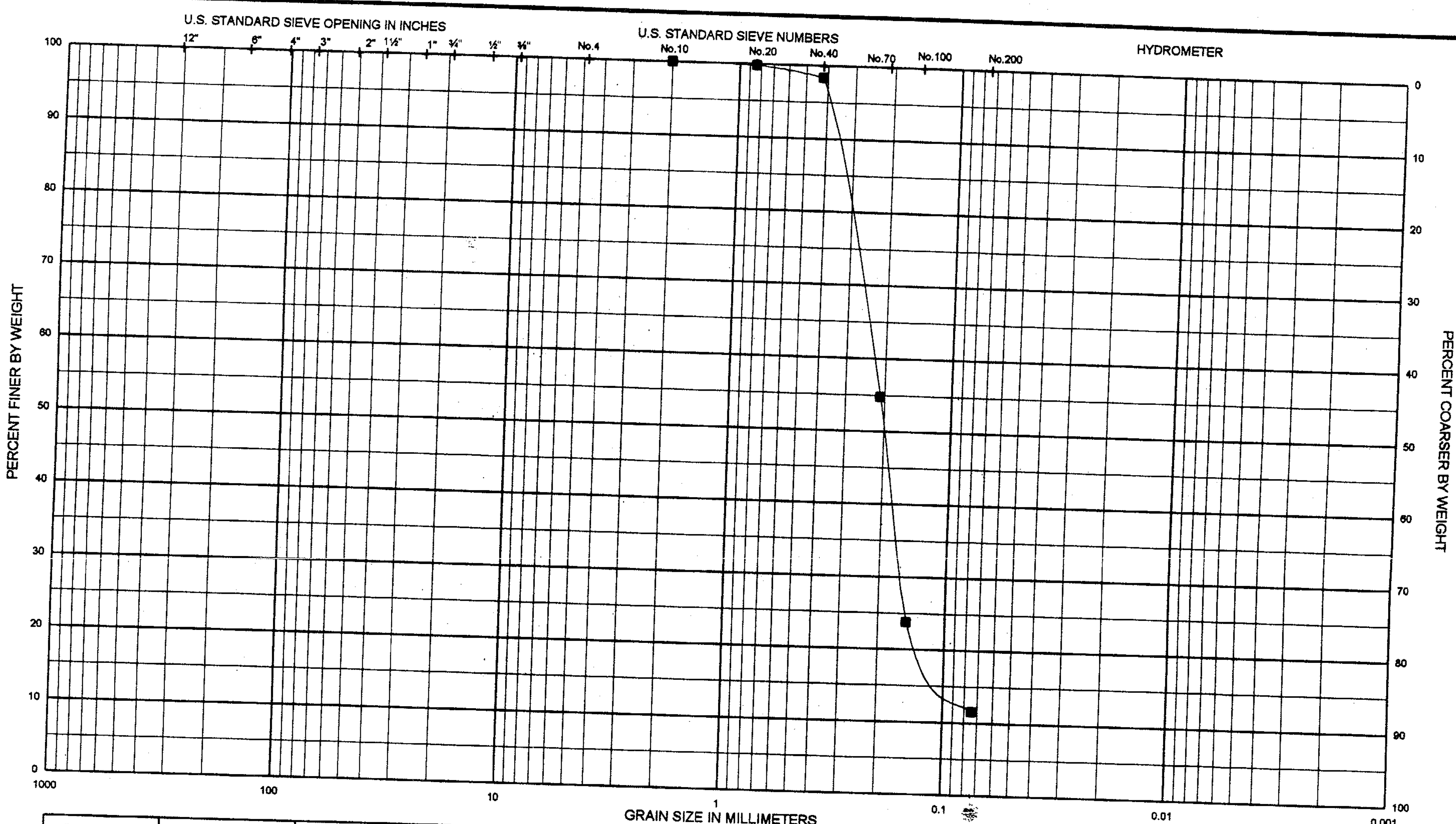
AREA: Somerset County, MD

Boring No.: NB-9

DATE: Jan 1999

ENG FORM 2087

GRADATION CURVES



Legend	Sample No.	Depth (ft)	Classification	Nat w%	LL	PL	PI
—■—	Jar-1	0.0-5.0	Poorly graded sand with silt $C_u = 4.4$ $C_c = 2.33$ (SP-SM)	—	—	—	—

PROJECT:	Smith Island Environmental Restoration Borrow Areas
AREA:	Somerset County, MD
Boring No.:	NB-11
DATE:	Jan 1999

ENG FORM 2087

GRADATION CURVES

SECTION 5

Project Design

STRUCTURE SECTION DESIGN

Standard Breakwater Section

Low crested structures such as those proposed for this project will generally be submerged during design storm events. Moreover, Van der Meer (1991) observed that overtopped breakwaters are more stable than non-overtopped breakwaters due to the fact that a large part of the wave energy can pass over the structure. Analysis of several data sets suggests applying a reduction factor to the median stone size to account for the increase in stability.

The procedure is to first establish the stability of the low crested breakwater assuming it is a non-overtopped structure. For the proposed breakwater design a nearshore 25-year wave height (H_{10}) of 5.8 feet and 25-year water level of 5.1 feet MLLW were used. Hudson's stability formula was then used to determine the required stone diameter as if it were a non-overtopped structure. The armor stone size was calculated using the ACES breakwater design computer program and was selected using the following equation:

$$W = \frac{W_r H_{10}^3}{K_D (S_r - 1)^3 \cot\theta}$$

where:

W = weight (lbs.) of individual armor unit in the primary core layer
W_r = unit weight of armor rock (165 lbs./cubic ft)
H_{10}= design wave height (5.7 feet)
S_r = specific gravity of armor unit relative to water (2.58)
θ = angle of structure side slope measured from the horizontal (degrees)
K_D= stability coefficient that varies primarily with the shape of the armor units, roughness of the armor unit surface, sharpness of the edges, and degree of interlocking obtained in placement. K_D values are selected for a breaking wave condition based on depths and slopes at the structure; K_D = 2.0

Based on a design wave height of 5.8 feet for the 25-year return period, the median stone weight is calculated to be 2600 pounds with a median stone diameter (D_{n50}) of 2.5 feet for the non-overtopped condition. Van der Meers reduction factor (r) for D_{n50} was then applied as follows:

$$r = 1/(1.25 - 4.8R_p^*)$$

for $0 < R_p^* < 0.052$

where:

R_p^* = dimensionless freeboard, $R_c/H_s(S_{op}/2\pi)^{0.5}$
R_c = crest freeboard, level of crest relative to still water level
S_{op} = fictitious wave steepness, $2\pi H_s/gT_p^2$
T_p = peak wave period

Using the above equation results in a reduction factor of .8 in the diameter of the median stone size required for the non-overtopped case. This results in a mean stone diameter of 2.0 feet, which equates to a median stone size of 1300 pounds. The range of weight of stone is 975 to 1625 pounds with at least 50% of the stones weighing more than 1300 pounds. The bedding layer stone was calculated to be W_{10}, or 130 pounds. The range of bedding stone is 90 to 170 pounds.

The crest width of the breakwater section was calculated from the equation:

$$B = nK_d(W_a/W_r)^{1/3}$$

where:

B = crest width (ft)
n = number of stones (3)
K_d= layer thickness coefficient (1.0)
W_a = weight of armor unit in primary cover layer
W_r = unit weight of armor unit (165 lb./cubic foot)

The minimum crest width was calculated to be 6.0 feet.

The thickness of the armor layer was computed from the equation:

$$r = nK_d(W_a/W_r)^{1/3}$$

where:

r = average thickness (ft)
n = number of layers (2)
W_a = weight of the individual armor unit (1300 lbs.)
K_d = layer thickness coefficient (1.0)

The armor thickness was calculated to be 4.0 feet or 2.0 feet per individual armor unit.

Sheet 15 shows a conventional structure with a 4-foot armor stone layer thickness (1300 pound stones), with 1.5:1 side slopes and a six-foot crest width. This structure would be appropriate for shorelines landward of the –2 or –3 foot contour. For soft bottom conditions it may be desirable to extend a one-foot minimum thickness of base stone beneath the armor stone to insure that individual stones do not sink into the bottom.

Reduced Volume Breakwater Section

This section was developed for offshore breakwaters at the Eastern Neck National Wildlife Refuge shoreline protection project, based on Value Engineering and model testing. The section is designed to be more easily constructed and to use less stone than the conventional structure. The base of the structure is a layer of Class II riprap, ranging in size from 20 to 700 pounds. The armor layers consist of stones with a minimum stone thickness of about 2 feet. The stones are laid with their minimum thickness perpendicular to the base (side of largest area laying flat on the base stone). This leads to a stable stone placement without extensive reworking of stone to provide a regular side slope surface.

With a minimum stone thickness of 2 feet and typical aspect ratios of 1.5:1 for the other two sides, a typical stone size would be 2x3x3 feet, or about 3000 pounds. With a maximum aspect ratio of 3:1 the largest stone would be 2x6x6, or 12,000 pounds. This stone would fit easily into the section laying flat on the armor stone (if the contractor chose to use such a large stone). In practice the allowable minimum stone thickness can range from 1.75 to 2.5 feet, allowing the crest to vary up to +1 feet over the specified elevation, while maintaining the specified crest elevation as the minimum allowed.

The reduced volume section requires approximately 20 percent less material for construction than the conventional structure. Sheet 16 shows a reduced volume structure.

Embankment Breakwater Section

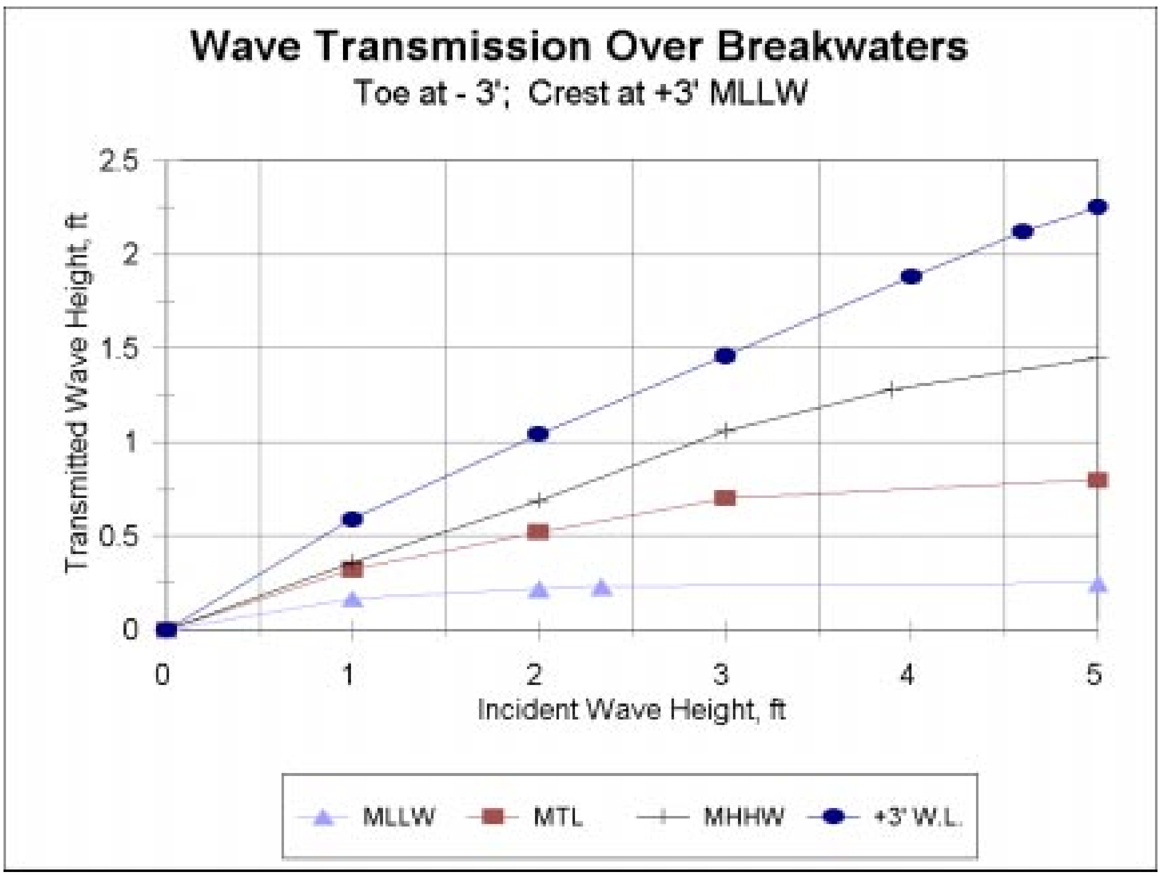
An alternative to the sand fill access road behind the nearshore breakwater is to design the breakwater itself to serve as the access road. In this case the structure would be wider than a typically designed nearshore breakwater to accommodate the required driving surface. Because of the volume of stone in the structure, it can be built with lighter than normal stone, and allowed to deform under storm wave action to a stable form with shallow seaward slopes. The smaller stones and large volume allows the structure to be built by end dumping, reducing the construction effort required as compared to a more typical structure. This type of structure was used for the Eastern Neck National Wildlife Refuge shoreline protection project in areas without shoreline access.

Wave Transmission

In general, the primary purpose of the breakwater section is to reduce the amount of wave energy reaching the shoreline in the lee of the structure. For constant wave conditions the amount of energy transmitted would primarily be a function of the structure crest height and to some degree the distance from the shoreline. The higher the crest elevation the lower the frequency of overtopping but at a higher cost. For this project the crest was picked to be about one foot above the eroding salt marsh edge elevation. Consequently, the structure crest is placed at +3 feet MLLW to protect the eroding salt marsh shoreline which is typically between +1 and +2 feet MLLW.

The figure below shows the height of the wave transmitted over a stone breakwater with a crest at +3 feet MLLW, built in a water depth of –3 feet MLLW, as a function of water level and incident wave height. The incident wave used for the calculations is the 50-year design wave with a period of 8.1 seconds. Because of the shallow depth at the toe of the structure, the incident wave is depth limited by wave breaking before it reaches the structure.

The transmitted wave heights were calculated using the ACES (Automated Coastal Engineering System, Version 1.07f), Wave Transmission Over A Permeable Structure. This routine only works for structures with a crest above the water level, so that submerged cases were not calculated. However, for very high water levels the shoreline is also submerged and the waves do not directly impact the eroding edge of the marsh, creating less severe erosion than the intermediate water levels.



It can be seen that the transmitted wave is less than half of the incident wave even with the water level at the crest of the structure. The effect of depth limitation of the design incident wave limits at the toe of the structure can also be seen.

Recommended Shore Erosion Protection Section

One of the design goals for wetland/restoration type projects is to use the minimum amount of structural protection necessary. For that reason, a low crest structure is proposed for shoreline protection measures along the Smith Island shoreline. As was discussed previously, a low crested structure will reduce the transmitted wave by 50% or more for frequent events. While not being as effective in attenuating the wave height during more extreme events, the impact to the shoreline will not be as significant, since the marsh shoreline will likely be inundated during such events. In such cases, the wave energy will pass over the marsh, and be dissipated, and not directly impact the marsh edge itself. Consequently, a structure crest height of +3 feet MLLW was selected for any shore protection measures. This is generally about one foot above the existing marsh shoreline. Additional cost savings can be realized by reducing the quantity of stone required in the cross-section while still achieving the same level of protection. Therefore, the reduced volume section (Sheet 16 Section 9) with a crest elevation of +3 feet MLLW is proposed to be the structural alternative utilized to provide shore protection to the eroding shorelines of Smith Island.

Jetty Sections

It is recommended that the crest of the jetties be placed at an elevation of +4.0 feet MLLW. This is about the 5-year recurrence elevation for storm surge, insuring that the crest will be above the still water level for most storm events, while maintaining an economical section for construction. A large portion of the bar over which the jetties will be built has a bottom between –2 and –3 feet MLLW. Therefore, over most of the jetty length the structure height will be between 6 and 7 feet.

For the jetty sections, 50-year return interval waves with a water level at the crest of the structure was chosen as the design condition. As discussed in the nearshore waves section, the nearshore H_{10} design waves range from 7.2 feet at the head of the jetty to 5.3 feet inshore of the –2.0-foot MLLW contour. This results in design stone sizes from 2000 pounds for the nearshore areas to 5200 pounds for the structure head. Because the structure crest is at the still water level for design conditions, the stone sizes can be reduced by 50 percent, since a large portion of the design wave energy will pass over the structure, reducing armor stone forces (van der Meer, 1993). However, because the section requires a certain thickness to achieve the desired crest height, it will often be as economical not to reduce the stone weight, and maintain a conservative design stone size. For the sake of consistency, the stone weight and associated cross section for the inshore jetty section was chosen to be the same as the conventional breakwater section (W_{50} = 1300 lbs). Using the same methods to determine the standard breakwater section and as described previously the W_{50} for the outer jetty section was determined to be 2600 pounds with a range from 1950 to 3250 pounds

It important to construct the jetties to be sand tight at least up to the +2 foot MLLW elevation over most of the jetty length. Because of the shallow depths, there will be significant sediment being transported by wave and current action adjacent to the jetties, which will move through a porous structure. In addition, it is likely that a portion of the jetty will have a fillet of material accumulate adjacent to the jetty. This can lead to large amounts of sediment moving through the jetty at the shoreline of the fillet. Seaward of the –3 or –4-foot contour the sand tightness of the jetty becomes less important.

There are several possible methods of increasing the sand tightness of the jetty section. The first, shown on Sheets 15 and 16 for both the conventional and reduced volume inner sections, consists of substituting a 2-foot high by 3-foot wide concrete block for one of the armor stones in the inner layer. By keying the concrete blocks end-to-end, a sand tight layer can be created. The same concept would apply the outer jetty section.

The cost of the concrete sand tightening could possibly be reduced by decreasing the width of the concrete block to two feet, or a narrow tapered unit similar to a “Jersey” traffic barrier could be used. For a narrow concrete unit consideration should be given to tying the individual units together.

A second method of creating a sand tight layer in the jetty section is the inclusion of a short length of vinyl sheet piling in the center of the section. An 8-foot section of piling could be driven with the top at +2 feet MLLW. The structure would then be built around the sheet piling, with the base stone and the armor stone piled adjacent to the piling. The top armor stone layer would cover the piling. The same concept would apply to the outer jetty section.

The selection of a sand tightening method should be based on the cost of materials and impacts on jetty construction.

Jetty Alignment

To assess the alignment of the proposed navigation improvement project at Sheep Pen Gut a two-dimensional flow model was utilized. The calibrated DYNLET model previously described provided the boundary conditions for the two-dimensional flow model at the southern, northern, and Sheep Pen Gut boundaries. It is assumed that the flow along the western boundary is zero, i.e. the flow in the offshore portion of the bay is strictly north-south in direction. The two-dimensional model covers an area 10,000 feet in the east-west direction and 8000 feet in the north south direction, with a 200-foot grid size. The model was run with typical tide stage time histories and storm tide time histories. Various geometries were simulated, including existing conditions, one jetty to the north of the proposed navigation channel, and two jetties protecting the proposed channel. Cases with and without the dredged channel were run to evaluate the ability of the channel to scour itself clear if it were to be filled by a major storm event.

The model provided two-dimensional flow patterns across the shallow bar in the area of the proposed channel, flow velocities through the channel for the various jetty configurations, and flow patterns in the vicinity of the proposed jetties. Representative vector plots are shown in Figures 1 through 3 for ebb currents for the cases of no jetty, one jetty, and two jetties.

Figure 1 – Ebb Current, No Jetty

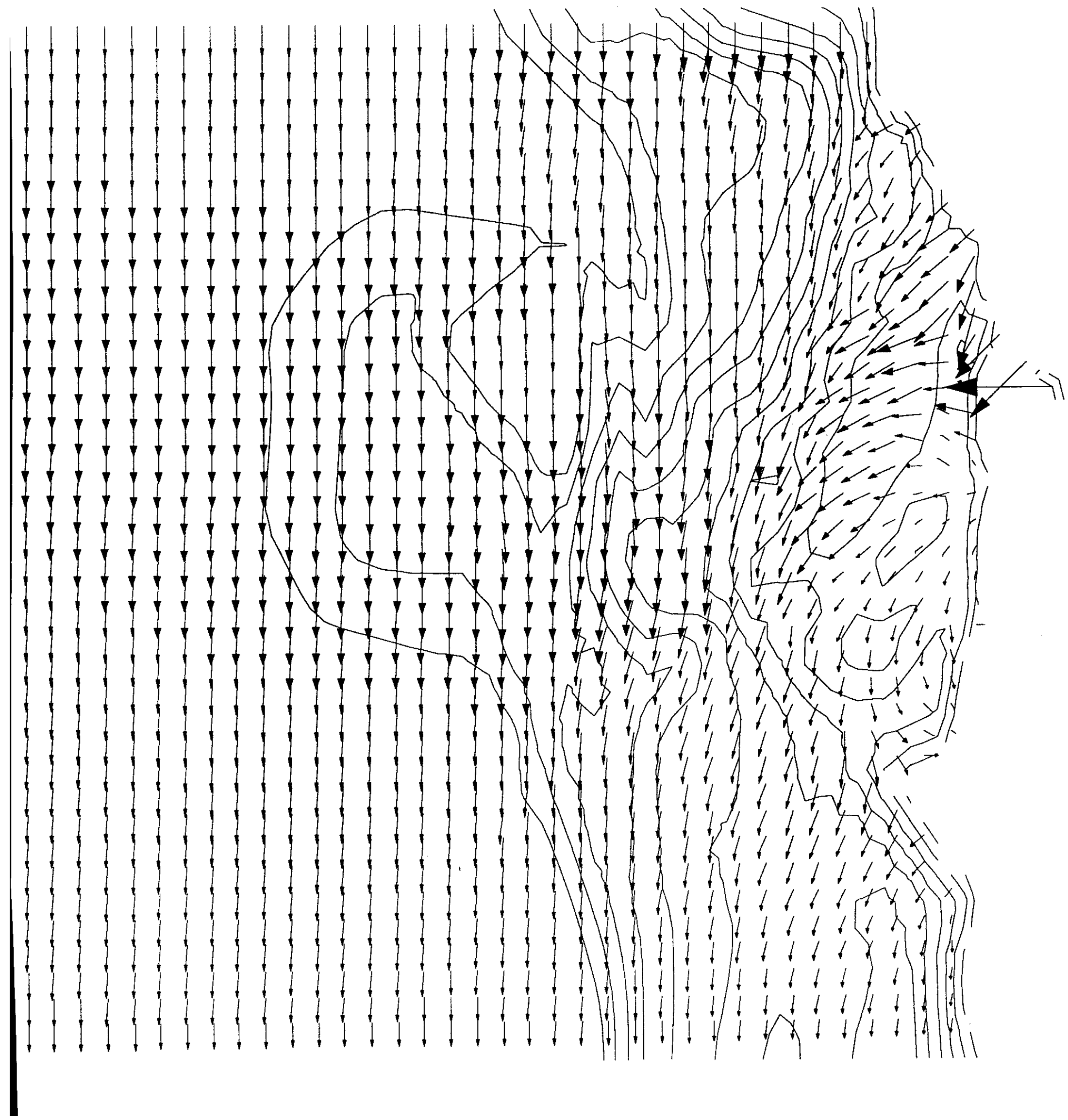


Figure 2 – Ebb Current, One Jetty

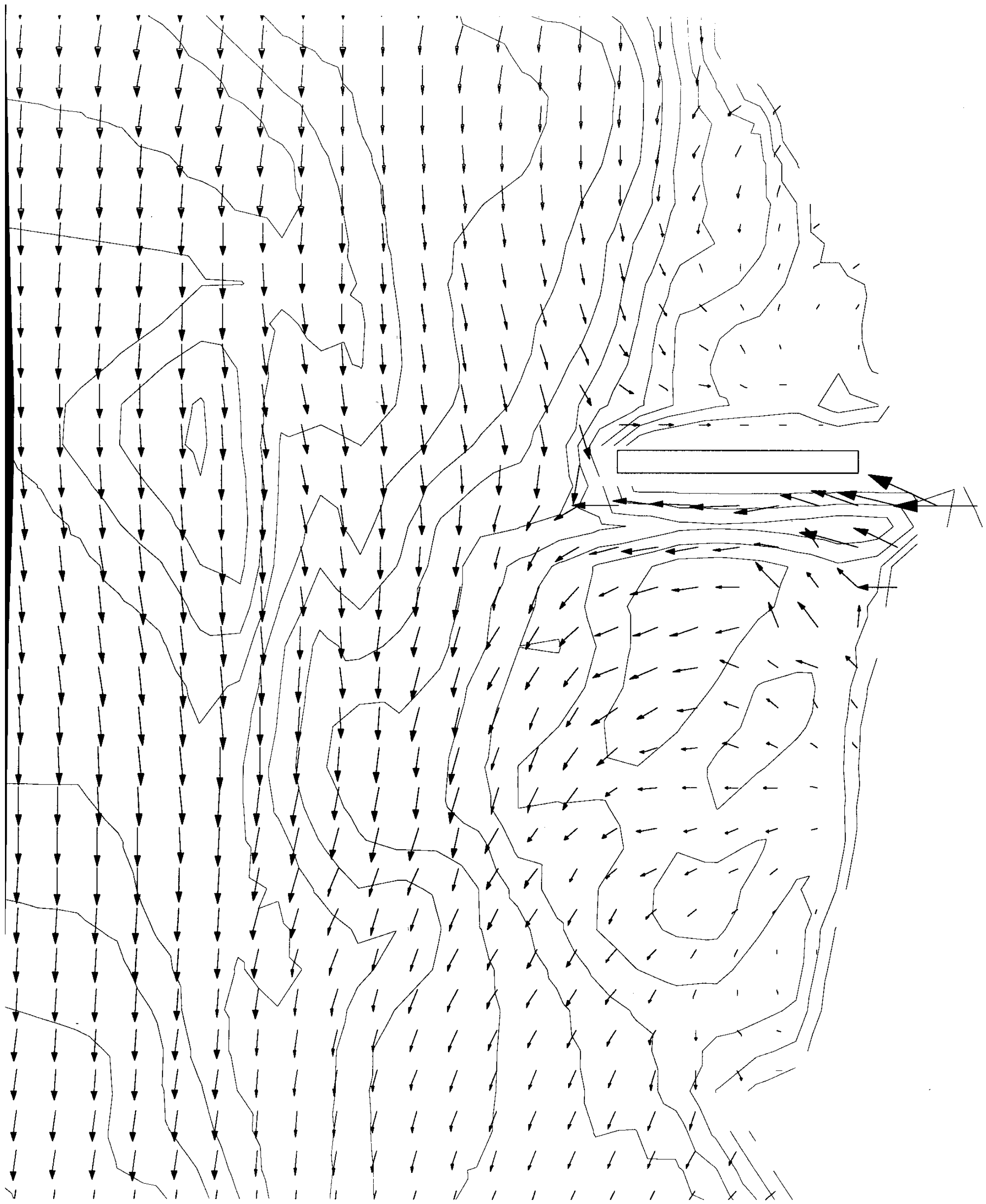
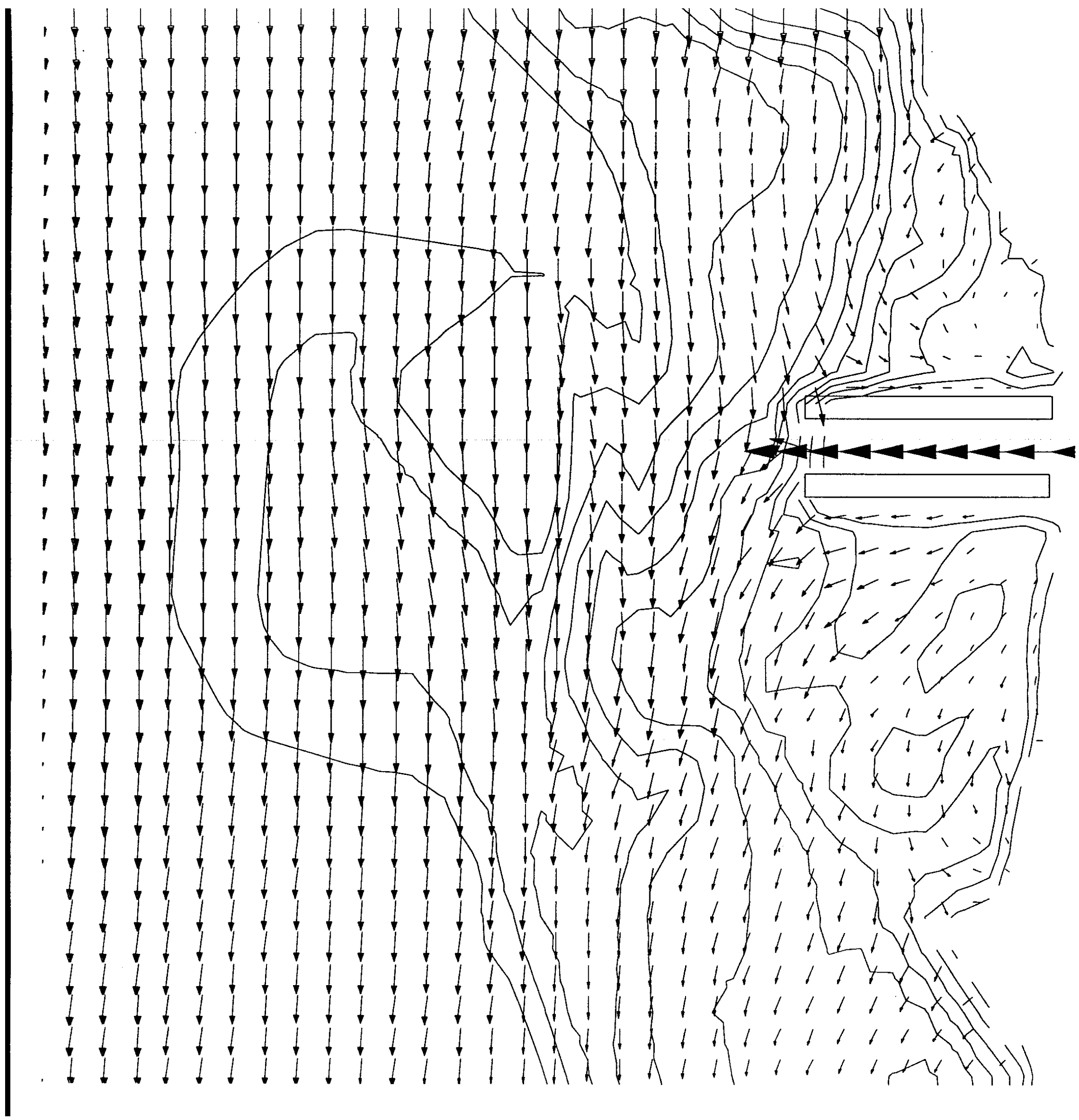


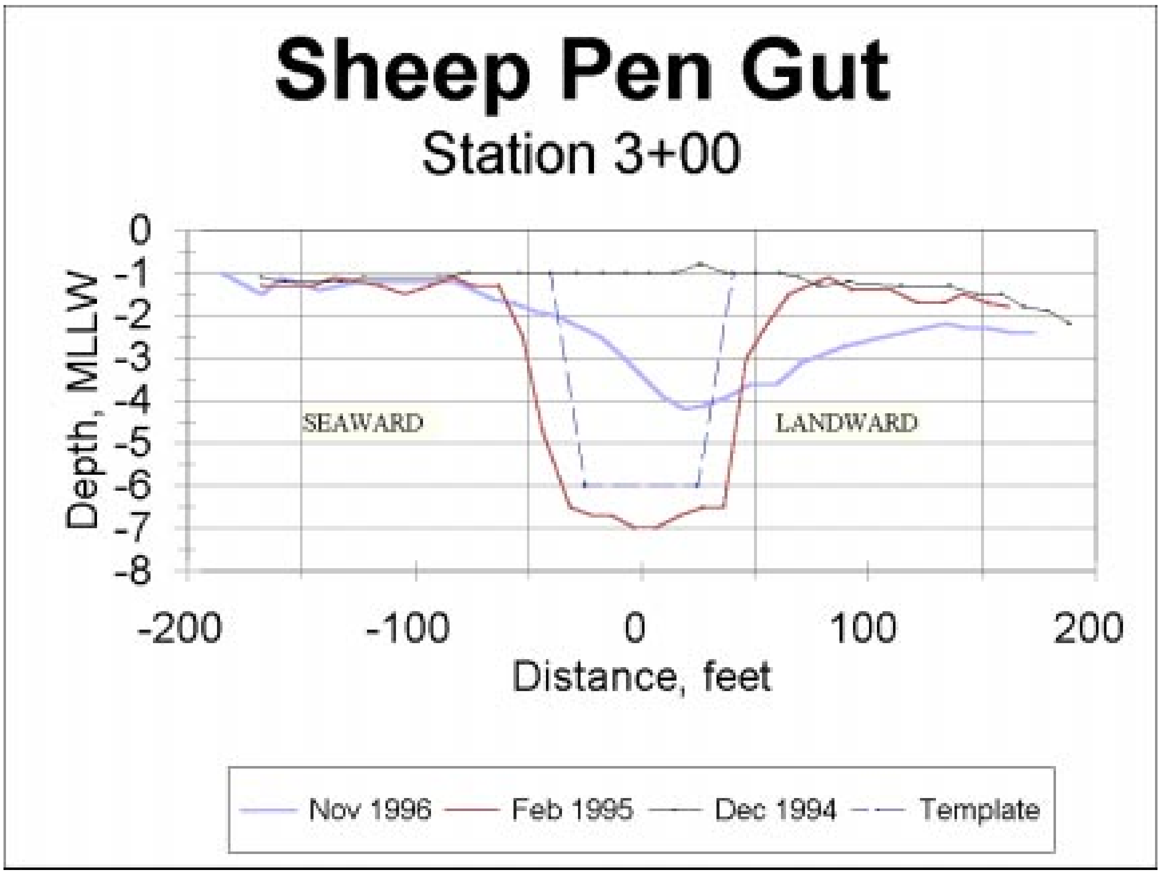
Figure 3 – Ebb current, Two Jetties



Channel Infilling Analysis

Surveys taken by the Baltimore District, Corps of Engineers, related to the existing navigation project at Sheep Pen Gut, have been examined for insights into channel infilling rates in the vicinity of Sheep Pen Gut. Of importance were surveys taken in December 1994, shortly prior to dredging the existing channel; February 1995, shortly after the channel was dredged; and November 1996, approximately one year and nine months after the channel was dredged. Representative survey sections across the channel were chosen for analysis in two locations. The first was at Station 3+00, which is representative of the portion of the existing channel that is parallel to the shoreline, and Station 5+00, which is representative of the portion of the channel that is perpendicular to the shoreline. The measurements, along with the theoretical channel template (channel bottom at –6 feet MLLW, 50 foot width at the bottom, 3:1 side slopes), are shown in Figures 4 and 5.

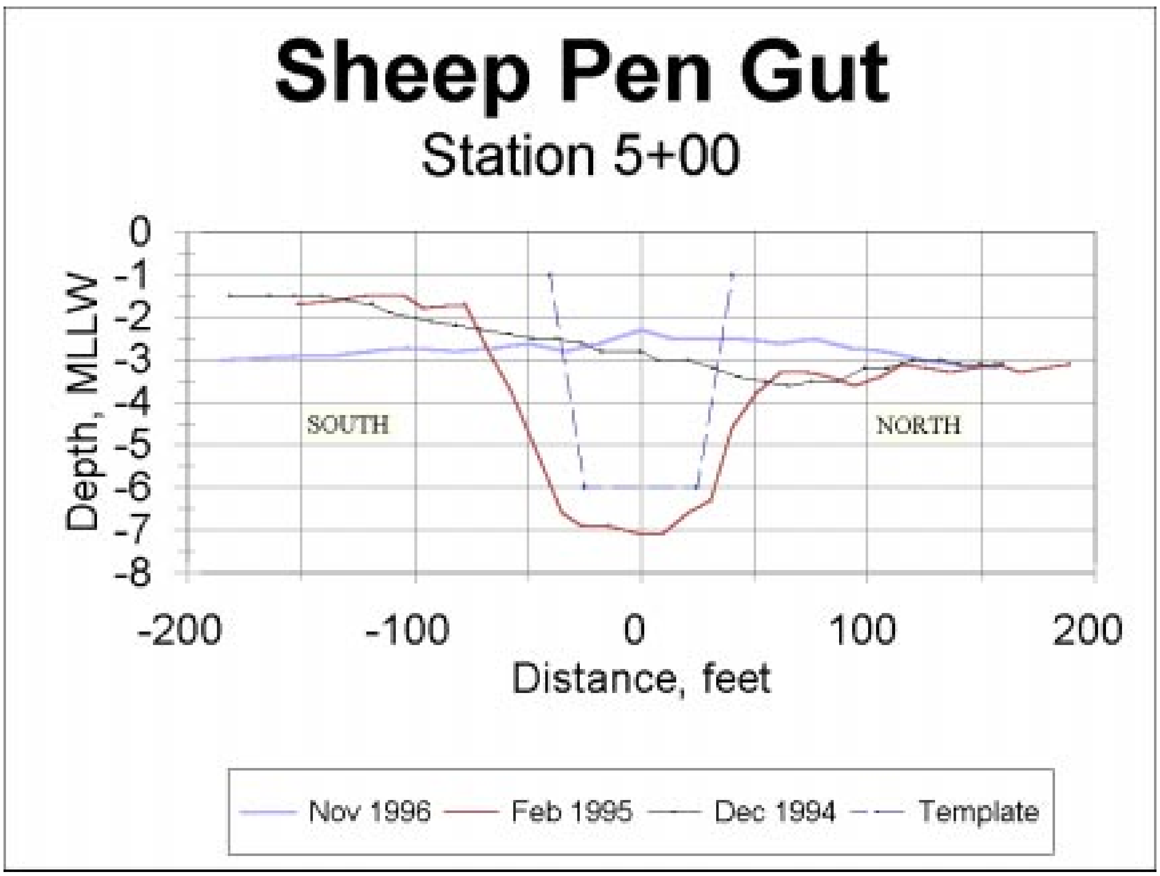
Figure 4



Analysis of the data from Figure 4 indicates that approximately 22 cubic yards per foot of channel were excavated during the dredging. Note that this included over-dredging to –7 feet MLLW and additional width as compared to the template.

Based on the conditions in November 1996 as compared to February 1995, approximately eleven cubic yards of material per foot had entered the channel in the 1-3/4 year period, resulting in an infilling rate of about six cubic yards per year. Because the channel filled completely on the seaward side of the channel and eroded on the landward side of the channel, it is apparent that there was a landward movement of material in this area.

Figure 5



The section at Station 5+00 filled completely between the dredging and the survey 1-¾ years later, in November 1996. Thus, an estimate of the infilling rate of the channel cannot be obtained, except to note that it is greater then 4.5 feet in 1-¾ years, or over 2.5 feet per year. Based on the measurements, it appears that the infilling in this case may have taken place from the south, since the bottom to the south of the channel has been eroded by the time of the November 1996 survey, relative to the previous surveys.

The channel proposed to replace the existing channel runs straight offshore, west-northwest, from the mouth of Sheep Pen Gut. This orientation is roughly the same as the offshore portion of the existing channel. Because the orientation, depths, tidal currents, and exposure to wave transport are similar, it is assumed that the infilling for the new channel would be similar to the offshore portion of the existing channel if it is not protected by a jetty. Jetties prevent the movement of current and wave driven sediment into the dredged channel, preventing infilling. In addition, the jetties can channel the flow, increasing the velocity of the tidal currents so that the typical tidal currents can scour out the channel if it begins to become filled in.

One of the items this study was asked to address is whether a single jetty could be configured to maintain the channel depths sufficient for navigation, either indefinitely or for a sufficiently long period to reduce the channel dredging requirements. It assumed that the most logical position for a single jetty is on the north side of the channel, since the wave driven transport is greatest from the north. The questions are then 1) how rapidly will a channel that is protected by a single jetty on its north side fill in, and 2) will normal tidal currents be sufficient to keep the channel scoured out, or can the tidal currents scour out the channel if it is filled in by a storm event.

1) Channel infilling:

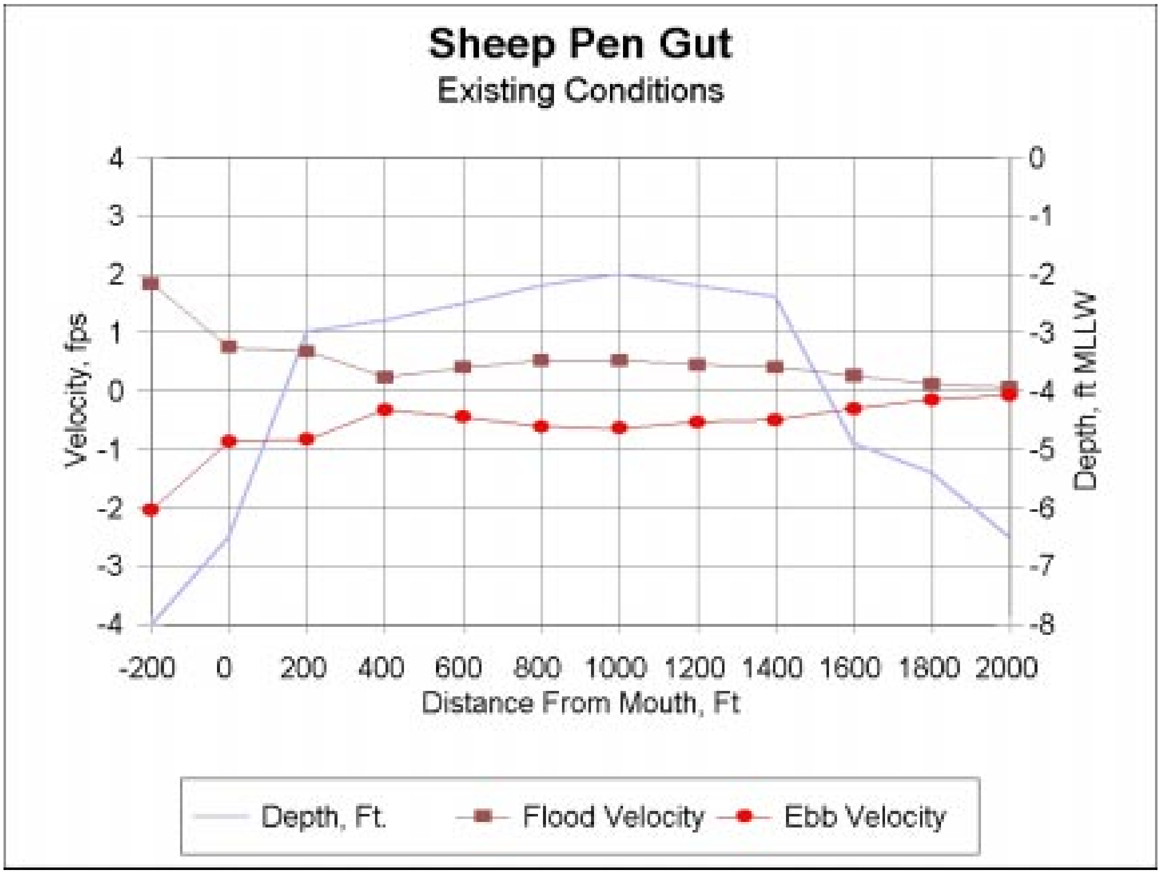
Previously in this report, the results of the numerical modeling indicated that the tidal currents are of similar magnitudes running in the north and south directions. Also, the wave driven sediment transport was found to be similar in magnitude for the northerly and southerly directions, with a slightly greater transport to the south. Because the outer portion of the existing channel apparently fills in very rapidly (probably within a year based on the survey results, and possibly much faster based on anecdotal reports from local watermen), it appears likely that a channel protected on the north will still fill in quickly. If the rate of infilling is cut in half by the jetty on the north side of the channel, the channel would still fill in within two years, and possibly much sooner.

2) Channel Scouring:

It is likely that the channel infilling takes place rapidly during a storm event, since typical tidal currents are not sufficient to carry large quantities of sediment. Therefore, it is necessary for the channel velocities to be great enough after the channel has been filled in by the storm to erode the material away. In order to assess the potential for channel scour for various channel and jetty configurations, the two-dimensional current model results were analyzed for current velocities along the channel centerline. The velocities for the peak ebb current and the peak flood currents were plotted along the proposed channel alignment in Figure 6 through 10. In addition to the current velocities, the channel depths were plotted in each figure.

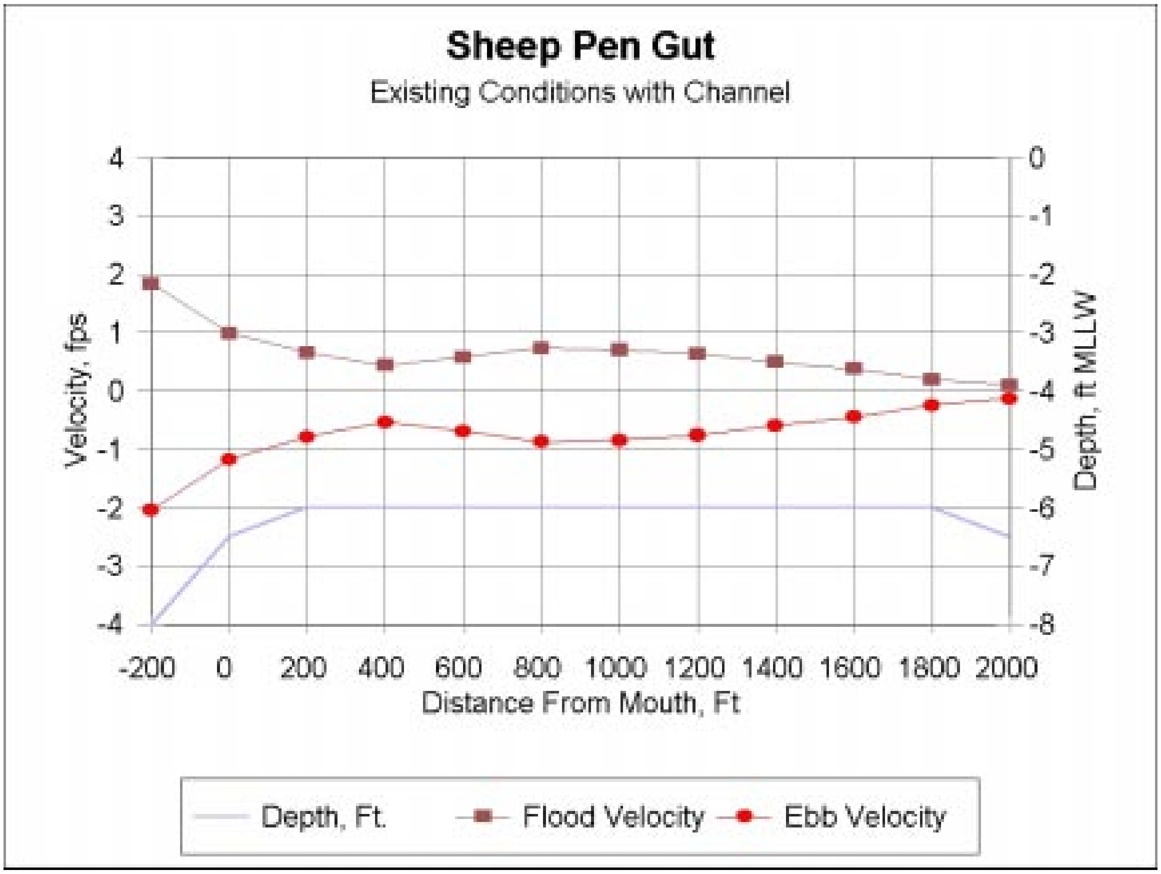
In Figure 6 the velocities along the channel alignment for the existing condition are plotted. The existing depths along the proposed channel range from –8 feet MLLW at the mouth of Sheep Pen Gut (at a distance of –200 feet from the mouth) to –2 feet at the midpoint of the channel before reaching –6 feet approximately 1900 feet from the mouth. Peak velocities range from about 2 fps at the mouth to less than 0.3 fps 400 feet from the mouth, as the flow diverges as it exits Sheep Pen Gut. The flow accelerates slightly as it passes over the shallow bar, and then slows again as it reaches deep water. As would be expected for the existing condition, the velocities are not sufficient to erode the bottom material, which would require velocities in the range of 0.8 to 1.0 fps for the fine grained material in this area.

Figure 6 – Tidal Velocities Along the Centerline of Proposed Channel
Existing Conditions



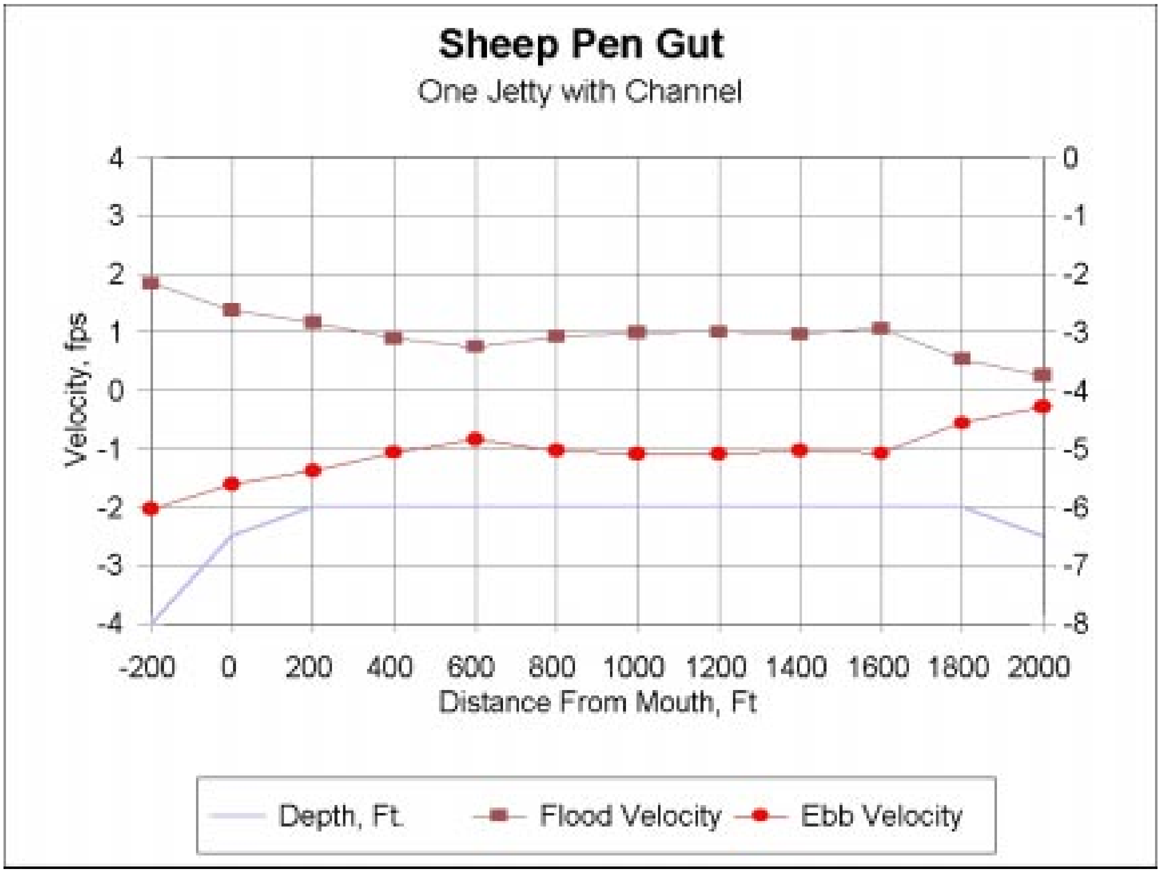
Although it is not proposed that a new channel be dredged through the bar from the mouth of Sheep Pen Gut directly to the west, this configuration would likely require less dredging, and remain open for navigation equally well as the existing, much longer channel. This condition was run with the two-dimensional model to determine if the tidal currents could maintain an open channel. The results are shown in Figure 7. It can be seen that the velocities drop below one-half fps near the mouth of the channel, before increasing in the middle of the channel as the flow across the shallow bar concentrates in the dredged channel. At the outer end of the channel the velocities drop as the flow spreads out over the deepening bar. This channel would quickly silt in at each end of the channel where the tidal velocities are below one-half fps. The channel also would not scour itself out when filled by a storm event.

Figure 7 – Dredged Channel, No Jetties



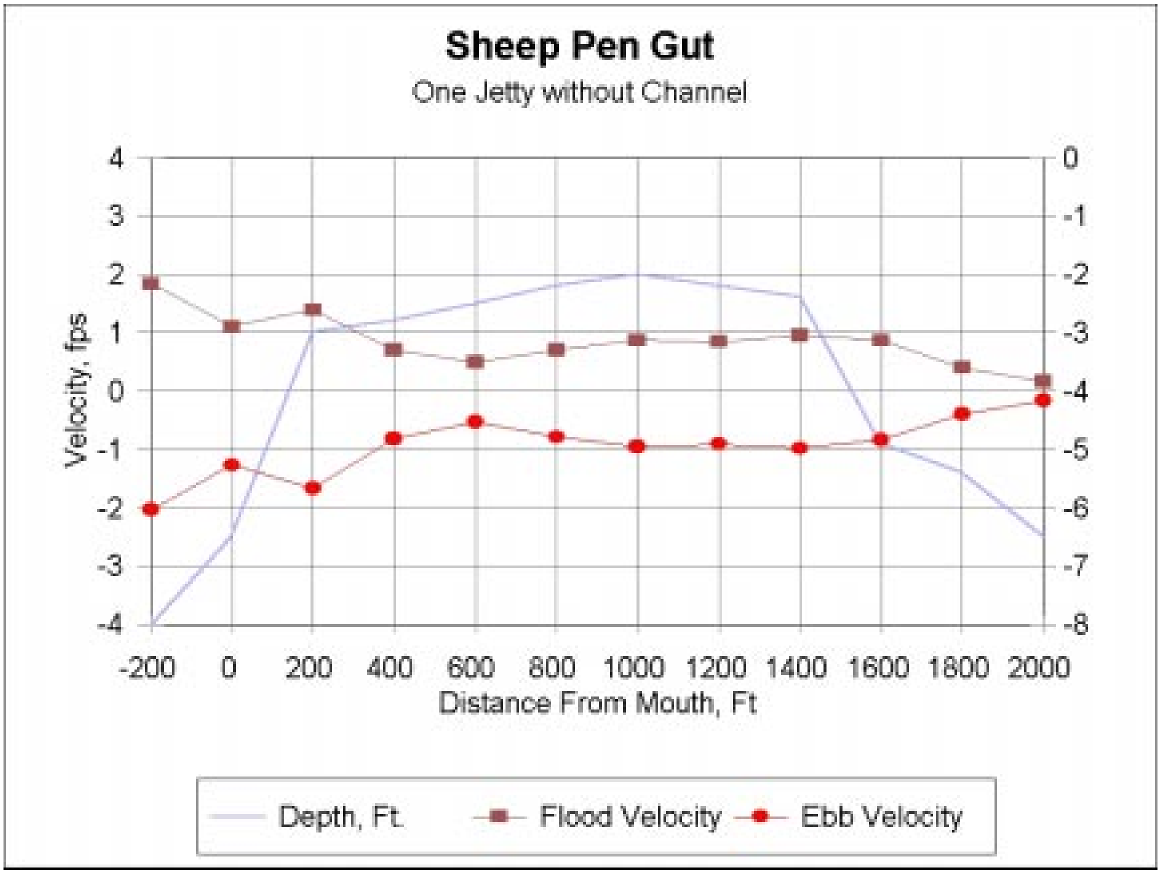
The case of one jetty on the north side of the dredged channel is shown in Figure 8. In this case the velocities have been increased between 40 and 60 percent over the dredged channel with no jetty, due to the partial confinement of the flow over the bar by the jetty. In this case the minimum velocity in the channel is about 0.8 fps, at the lower limit of scour for the bottom material in the vicinity of the channel. Typical tidal velocities are about 1.0 fps. Therefore it is likely that the dredged channel protected by a single jetty would maintain itself during normal conditions.

Figure 8 – Dredged Channel, One Jetty



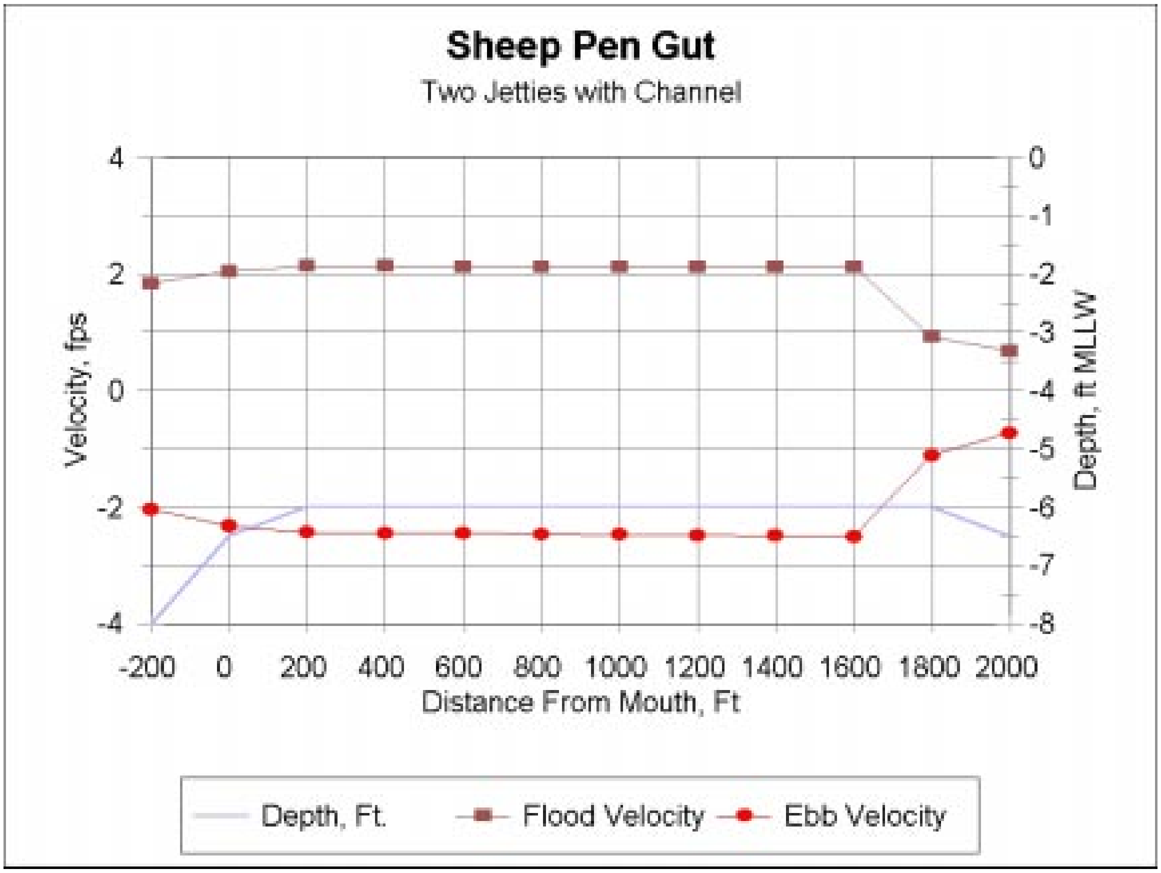
The case of one jetty with a filled in channel is shown in Figure 9. This represents the situation after the channel has been filled with sediment by a storm event. In this case the velocity drops to about 0.5 fps near the mouth, but in general remains above 0.8 fps over most of its length. Therefore, it appears that the ability of the channel with one jetty to scour itself out after a storm event is marginal. The area near the mouth with the low velocities may not scour naturally after a storm event.

Figure 9 – Filled Channel with One Jetty



As a final configuration, the case of two jetties with the dredged channel is shown in Figure 10. In this case, the velocities increase slightly after leaving the mouth of the channel because the dredged channel has somewhat less cross-sectional area than does the existing natural Sheep Pen Gut channel. The velocity remains relatively constant because the jetties prevent the spreading of the current over the surrounding bar. For the case of two jetties with a filled channel (not shown), the velocities increase even further because of the reduced cross-section of the channel and the confinement of the jetties. In this case, the channel can scour itself over its entire length.

Figure 10 – Dredged Channel, Two Jetties



In conclusion, it appears that the one jetty configuration is marginal in terms of maintaining its channel without regular maintenance dredging. Typical storm activity will deposit sediments into the channel, and the normal tidal velocities may not be sufficient to scour out the channel. It should be expected that dredging would be required on at least a two-year cycle to maintain the navigation channel. The channel would likely become filled during a major storm event, and remain filled until a dredge operation was mobilized

The two jetty configuration should be able to maintain an open channel under all conditions, requiring only limited maintenance dredging, if any. To be conservative, limited maintenance dredging should be assumed on an eight to ten year cycle. This maintenance dredging would likely require less volume than the full channel dredging currently required.

Sheep Pen Gut Jetty and Shore Protection Layout

Based on the results of the numerical modeling and the bathymetry from 1998 provided by the Baltimore District, Corps of Engineers, a jetty and shoreline protection layout for the vicinity of Sheep Pen Gut is shown on Sheets 3 and 4.

The jetties consist of a 1550-foot north jetty and a 1900-foot south jetty. The jetties are placed a minimum of 200 feet apart to provide adequate room for the channel and possible enlargement of the channel due to natural scour. The dredged channel would be about 1500 feet long, requiring approximately 25,000 cubic yards of dredging.

Dredge spoils could be placed in the fillet to the north of the jetties, providing shoreline protection and creating approximately 2 acres of marsh if planted with appropriate vegetation. South of the jetties four offshore segment breakwaters are proposed. This material should be stable, except for winnowing of fine silt sized particles along the shoreline, because it is confined from movement by waves and currents from the north by the jetty to its south, and protected from waves and currents from the south

Erosion protection for the shoreline to the south of the jetties could be provided by offshore segmented breakwaters. As drawn, the breakwaters are 225 feet long with 125-foot gaps, placed approximately 200 feet from the shoreline between the gaps. The breakwaters were sized and placed to take advantage of the existing shoreline irregularities. Additional channel dredge material could be placed along the shoreline to provide a sand beach and possible additional marsh area.

Possible refinements to the plan might include shortening the jetties by 100 to 150 feet to eliminate the portion of the jetties deeper than –4 or –5 feet MLLW. Based on the mouth of the existing gut, it appears that the tidal currents exiting the confines of the jetties would be sufficient to maintain the design channel depths for 100 to 150 feet beyond the ends of the jetties. This would remove the most expensive and vulnerable section of the jetties, reducing costs and maintenance.

If funds were not sufficient to construct both jetties in their entireties, one option would be to reduce the length of the south jetty. Based on the numerical modeling, a single jetty was marginal in terms of maintaining a navigation channel without maintenance dredging. Constructing the jetty out beyond the –2 foot contour would greatly help in maintaining the channel, by eliminating the area of lowest currents. This at least would decrease the amount of required maintenance.

Swan Island Shoreline Protection

The Swan Island/Silver Island area has been proposed for nearshore breakwater shoreline protection with marsh creation in the existing gut between Swan and Silver Islands. This area will require either water-based construction, a barge access causeway, or dredged barge channel.

One possibility is to construct a causeway or channel near the center of the construction reach, and import fill for a staging area at the base of the causeway, as shown in the figure in the previous section. The advantage of this location is that construction-hauling distances are minimized by the central location of the causeway, and deep water is relatively close to the shoreline. The causeway would be on the order of 1000 to 1200 feet in length. After construction is complete the staging area material would be distributed over a larger area to an elevation suitable for marsh and planted with marsh grasses.

A proposed shoreline protection layout is shown on Sheets 5 through 7. In the proposed layout, the nearshore breakwater has been placed approximately 30 feet from the more seaward protruding portions of the shoreline, to provide room for the access road. Gaps have been placed in the nearshore breakwater at areas where the natural shoreline indentations provide greater distance from the proposed structures. The gaps are on the order of 70 to 90 feet long. The gaps provide a more natural shoreline by providing access to the sand beaches, instead of a continuous stone structure, and also reduce the 7volume of stone required to protect the shoreline.

An approximate shoreline has been sketched on the Plate representing the sand from the access road after being graded into a natural beach and redistributed by wave action. It is anticipated that behind the gaps the beach will form into a stable concentric shape. The higher portions of the beach could be planted with marsh grasses for more erosion protection.

Areas of the shoreline where cuts into the marsh occur could be further protected by constructing sand dunes planted with dune grass. By making the dunes somewhat higher than the natural dunes in the area, overtopping and washover into the cuts could be minimized.

The area between Swan and Silver Islands could be protected with a small sill on the landward boundary of the area to be converted to marsh. Locally obtained or imported material could then be used to fill the area to the desired marsh elevation.

The most northerly portion of the shoreline segment leading to Fog Point has not been mapped at this point. The location of the nearshore breakwater in this area is based on the offshore bathymetry for the area. Once mapping is complete, additional gaps may be appropriate based on the configuration of the shoreline.

This area has been proposed for offshore breakwaters protecting the shoreline along Fog Point Cove and providing SAV habitat behind the offshore breakwaters. Deep water for construction access can be found off of Fog Point. A causeway with a length from 1200 to 1500 feet would be required to reach depths of 10 feet. An alternative to the causeway construction at Fog Point would be to use the construction access provided for the Swan Island shoreline protection, if the shoreline protection extended far enough north along the shoreline to Fog Point. It might be more economical to extend the shoreline protection than to have to pay additional mobilization for causeway construction at Fog Point. It may be most economical to construct the offshore breakwaters from shallow draft barges. In this case the breakwaters should be placed in slightly deeper water to allow easier access by barge, at the cost of additional material due to a higher required structure.

A layout of offshore segmented breakwaters along the –2 to –3 foot contour is shown on Sheets 9 and 10. The breakwater lengths and gap lengths were drawn arbitrarily in the figure. For final design, the ratio of the breakwater length to gap length should be chosen to obtain the percent wave energy reduction desired. Because the storms that impact this area come from the north, the water levels associated with the storms are typically lower than normal. For these storms, wave overtopping will be a minor contribution to the total wave energy behind the breakwaters. Therefore the reduction in wave energy can be estimated by the ratio of the breakwater length to the gap length. If a 50% energy reduction were desired, the gap length would be made equal to the breakwater length. If a 67% energy reduction were desired, the gap length would be made one-half of the breakwater length. The actual breakwater length can be set to be convenient for construction, typically between 100 and 200 feet.

It has been suggested that the most cost effective protection for this area is to protect the points of land at each end of the cove, so that the cove does not gradually disappear due to erosion, but not try to protect the entire area of the cove. In this case only one or two of the segmented breakwaters need to be constructed at each point, possibly with a limited amount of beach fill and marsh plantings for additional protection. For isolated structures, shallow barge construction will be the most economical.

Back Cove and Terrapin Sand Point Protection

Sheets 11 through 14 show the Back Cove, Terrapin Sand Point, and the Bards Point to Fishing Point areas. The priorities for shoreline protection for these areas had not been set at the time of the present study, so only general information on these areas is presented.

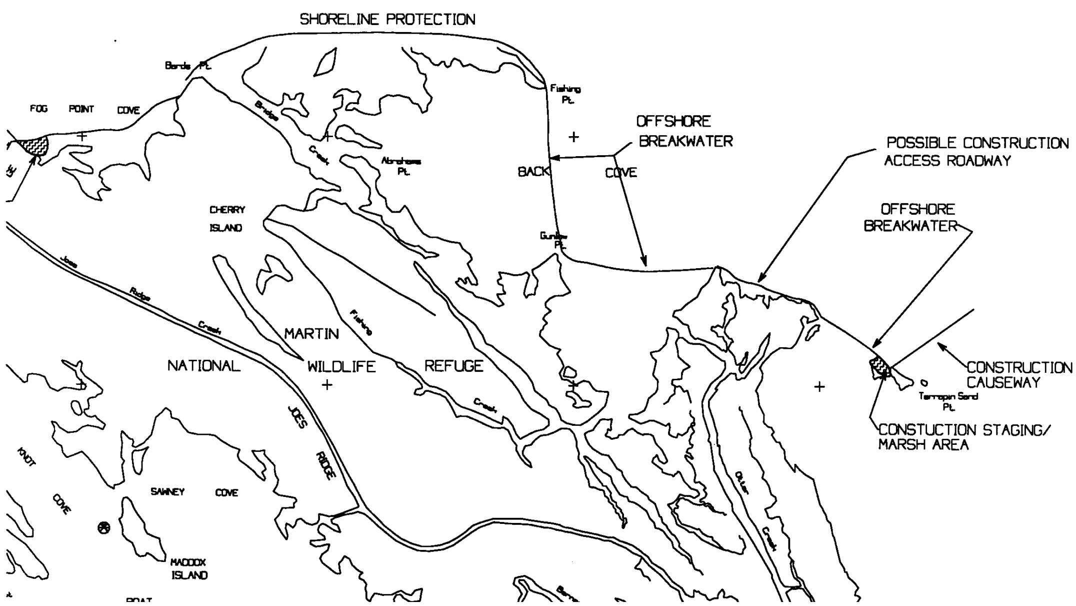
These areas are in close proximity, and if shoreline based construction is to be used they should probably be connected with a construction access roadway so that a single construction causeway and staging area could serve all areas. The closest area of deep water is off of Terrapin Sand Point. Access to the Back Cove area would require a much longer causeway because of the location of deep water. Less information on offshore water depths and shoreline configuration is available for the Bards Point to Fishing Point area because mapping and bathymetric surveys have not yet been done for this area

The offshore breakwaters could be constructed using an access road along the alignment of the breakwaters, with the material removed and used for marsh creation or enhancement of the islands at Terrapin Sand Point or some other area. Alternatively, the breakwaters could be constructed by using the structures themselves as access roads.

Another alternative for these areas is to keep the breakwaters in deep enough water so that barge construction is feasible.

For the nearshore breakwater areas, it is recommended that shoreline protection be laid out in a similar manner as the Swan Island shoreline protection described previously, once shoreline configuration information is available. For preliminary estimates, the average volume of stone and fill required per foot of shoreline derived from the Swan Island shoreline can be used. The distance from the shoreline to deep water will determine the feasibility of shoreline construction access versus shallow water barge access. This should either be determined after additional mapping is done, or left to the discretion of the contractor.

Figure 15 – Back Cove and Terrapin Sand Point
Shoreline Protection Layout



SECTION 6

Construction Procedure

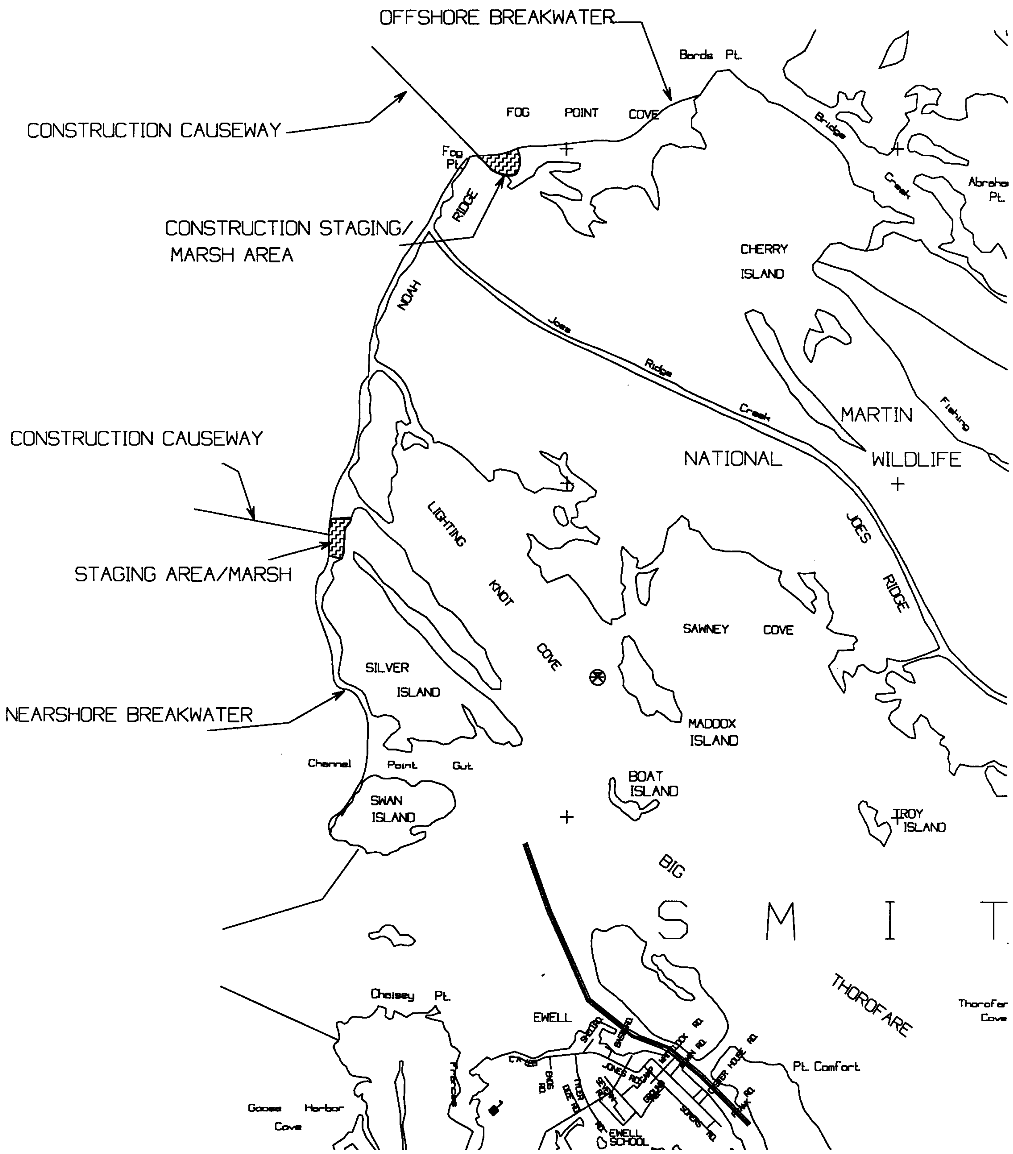
Construction Issues

Due to the lack of land access for much of the project area, constructibility will govern the design and cost of the proposed protection structures as much as the other design criteria. Construction materials will have to be transported to the island by barge, and then carried to the shoreline or shallow nearshore area where the construction will take place by shallow draft barge, causeway or dredged channel. Because the shoreline of Smith Island will not support construction activities, the shore protection structures must be designed so that the contractor can build the structures from shallow water barges, use the structures for access, or have room to build an access road adjacent to the structure. In the latter case provision should be made for using the access road material as part of the project so that the material does not have to be removed and transported off island at the end of the project. The compatibility of various potential access road fill materials with the local environmental should be considered at the feasibility level so that appropriate materials can be incorporated into the project. For example, sand fill might be appropriate for an access road behind a nearshore breakwater, where it could be eventually graded and planted to create marsh. On the other hand, sand might not be appropriate for offshore breakwater construction roads where it may be detrimental to the growth of SAV if left to spread out over the existing bottom. The Figure 1 shows a conceptual layout and construction plan for the Swan/Silver Island area.

In this figure it is assumed that the contractor has chosen to construct the project by building causeways from the –8 to –10 foot water depth to the shoreline to provide access to the project. A sand access road is used to construct the shoreline erosion protection structures. After the structures have been completed, the sand access road would be graded into a natural beach, and the upper elevations would be planted with marsh grasses, providing additional protection to the eroding shoreline.

It is also possible to design structures that are suitable for initially hauling construction materials along the shoreline or offshore breakwater alignment until the end of a construction area is reached, as discussed in Section 3.3. The structure can then be left to provide the required level of shoreline protection, or reworked by the addition of larger armor stones on the seaward side and crest, as the equipment is withdrawn back to the construction staging area. While the amount of material required for such a structure will be greater than that required for more typical nearshore or offshore breakwaters alone, there might be savings when compared to the additional cost of constructing a separate construction access road. This method worked well for the southerly extension of the Eastern Neck Island Shoreline Protection Project at Kent Island, Maryland.

In addition, the contractor will require construction staging areas for equipment storage, fueling, material handling, construction trailer, etc. Due to the lack of upland areas along much of the project, these areas may have to be constructed from imported fill. The required staging area and potential volume of fill should be considered in the early stages of design so that the fill can be incorporated into beneficial uses such as protected marsh areas.


OFFSHORE BREAKWATER
CONSTRUCTION CAUSEWAY
CONSTRUCTION STAGING/
MARSH AREA
CONSTRUCTION CAUSEWAY
STAGING AREA/MARSH
NEARSHORE BREAKWATER
Bards Pt.
FOG POINT COVE
Fog Pt.
RIDGE
NOAH
Bridge
Creek
CHERRY
ISLAND
Joes
Ridge
Creek
MARTIN
NATIONAL
WILDLIFE
Fishing
JOES
RIDGE
LIGHTING
KNOT
COVE
SAWNEY COVE
SILVER
ISLAND
MADDOX
ISLAND
Channel Point Gut
SWAN
ISLAND
BOAT
ISLAND
TROY
ISLAND
BIG
S M I T
THOROFARE
Thorofar
Cove
Choisey Pt.
EWELL
Pt. Comfort
Goose Harbor
Cove
EWELL
SCHOOL

SECTION 7

Quantity and Cost Estimates

The following quantities and costs were developed for the proposed projects as depicted on the drawings in Section 9:

Project Area	Description	Key Quantities	Cost
Rhodes Point	*Conventional Structure*		$2,370,000
	Twin Jetties	12,570 CY Stone	
	Channel Dredging	18,470 CY	
	Breakwaters	3,970 CY Stone	
	Backfill/Plantings	18,470 CY/2.0 Acres	
	Reduced Volume Struc.		$1,936,000
	Twin Jetties	10,810 CY	
	Channel Dredging	18,470 CY	
	Breakwaters	4,330 CY Stone	
	Backfill/Plantings	18,470 CY/2.0 Acres	
Western Shoreline	Breakwaters Backfill/Plantings	17,300 CY Stone 15,000 CY/7.5 Acres	$2,569,000
Fog Point Cove	Breakwaters & Contin. Structure Backfill/Plantings	6,600 CY Stone 13,000 CY/3.6 Acres	$1,398,000
Back Cove	Breakwaters & Contin. Structure Backfill/Plantings	18,400 CY Stone 40,000 CY/15.0 Acres	$2,839,000
Terrapin Sand Cove	Breakwaters Backfill/Plantings	297,600 CY Stone 4,500 CY/1.0 Acres	$30,336,000

Note:

- Quantities and costs for the Western Shoreline, Fog Point, Back and Terrapin Sand Coves are for the reduced volume structures.
- Effective pricing level is 1 October 2000.
- Construction management costs and a 20% contingency are included in the cost.
- Real estate and preconstruction engineering and design (PED) costs are not included in the cost.

SECTION 8

Future Design Effort

Additional surveys and mapping will be required for final design, quantity estimates, and preparation of the contract drawings. A combination of hydrographic and land surveys will be required in each of the project areas. Depth measurements in shallow water should be performed by a surveyor rather than a boat; hydrographic surveys are inaccurate in shallow water. The additional surveys are required to obtain mapping in areas not previously surveyed, supplement previous mapping, and identify any changes in existing landforms and channel bottom. With the eroding shoreline and changing bottom conditions, it is critical that updated and accurate mapping be obtained and used for final design. Additional mapping will also provide a good reference to compare with the previous mapping and will serve as a baseline for monitoring post project conditions.

Further design is required, particularly for the proposed breakwaters and backfill and plantings. The appropriate spacing between each segmented breakwater, length of each breakwater, distance offshore and final cross-section must be carefully analyzed and the appropriate dimensions determined. Location and placement of backfill (assuming the material is available) also requires further analysis, as does appropriate planting zones and species to use.

A detailed monitoring plan should be prepared during final design. This plan should include at a minimum photographs and some surveys of the project areas at designated periods after construction. Ideally, aerial photography, detailed surveys of the shoreline and water depths, and vegetation and wildlife analysis would also be performed. A comprehensive monitoring plan would provide invaluable data on the effectiveness of the new structures, backfill, and plantings. Appropriate project modifications would be based on the monitoring results, and future designs could incorporate the lessons learned from the Smith Island project. The "Monitoring Study, Eastern Neck Island National Wildlife Refuge" dated October 1995 is an example of a monitoring effort for a project similar to that proposed for Smith Island. Mr. John Gill, U.S. Fish and Wildlife Service, and the U.S. Army Engineer Waterways Experiment Station jointly worked on the study.

Future geotechnical work will include additional drilling, testing, and design for the selected alternatives. Foundation drilling will be required for the offshore structures selected to be built. Some of the initial exploratory drillholes encountered large clay deposits. Samples will have to be obtained of the clay in order to perform laboratory consolidation tests. The structures can then be effectively designed for the foundation conditions identified. Specifications will be written for appropriate areas of work, such as stonework and geotextile.

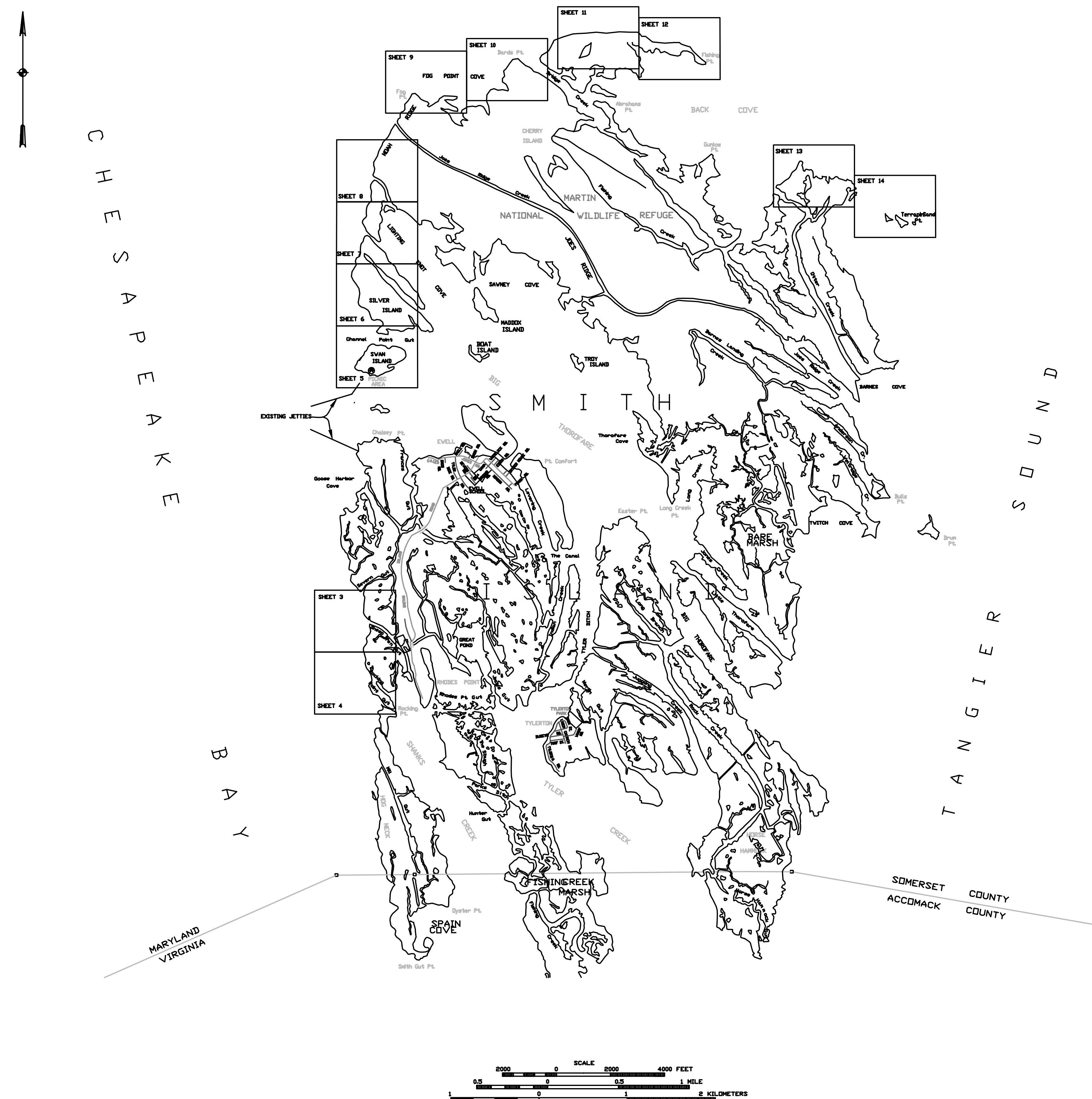
Additional borrow exploration and analysis will be required to determine if there is suitable material obtainable for placement behind offshore erosion protection structures. Current borrow material exploration and analysis is not adequate to definitively identify adequate sources of borrow material. The borrow sources must also be approved by the appropriate resource agencies. National Marine Fisheries Service (NMFS), has said that approval for offshore borrow material will not be granted unless it can be shown that all other options had been adequately explored and ruled out.

SECTION 9

Plates, Figures, and Drawings

LIST OF DRAWINGS

Sheet No.	Title
1	Site Map and Plan Legend
2	Borrow Investigation Map
3	Rhodes Point Plan
4	Rhodes Point Plan
5	Western Shoreline Plan
6	Western Shoreline Plan
7	Western Shoreline Plan
8	Western Shoreline Plan
9	Fog Point Cove Plan
10	Fog Point Cove Plan
11	Back Cove Plan
12	Back Cove Plan
13	Back Cove Plan
14	Terrapin Sand Cove Plan
15	Typical Sections – Conventional
16	Typical Sections – Reduced Volume
17	Spectral Imaging – Fog Point Cove
18	Spectral Imaging – Back Cove



AREA	SHEET NOS.
RHODES POINT	3,4
WESTERN SHORELINE	5,6,7,8
FOG POINT COVE	9,10
BACK COVE	11,12,13
TERRAPIN SAND COVE	14

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SOMERSET COUNTY, MARYLAND
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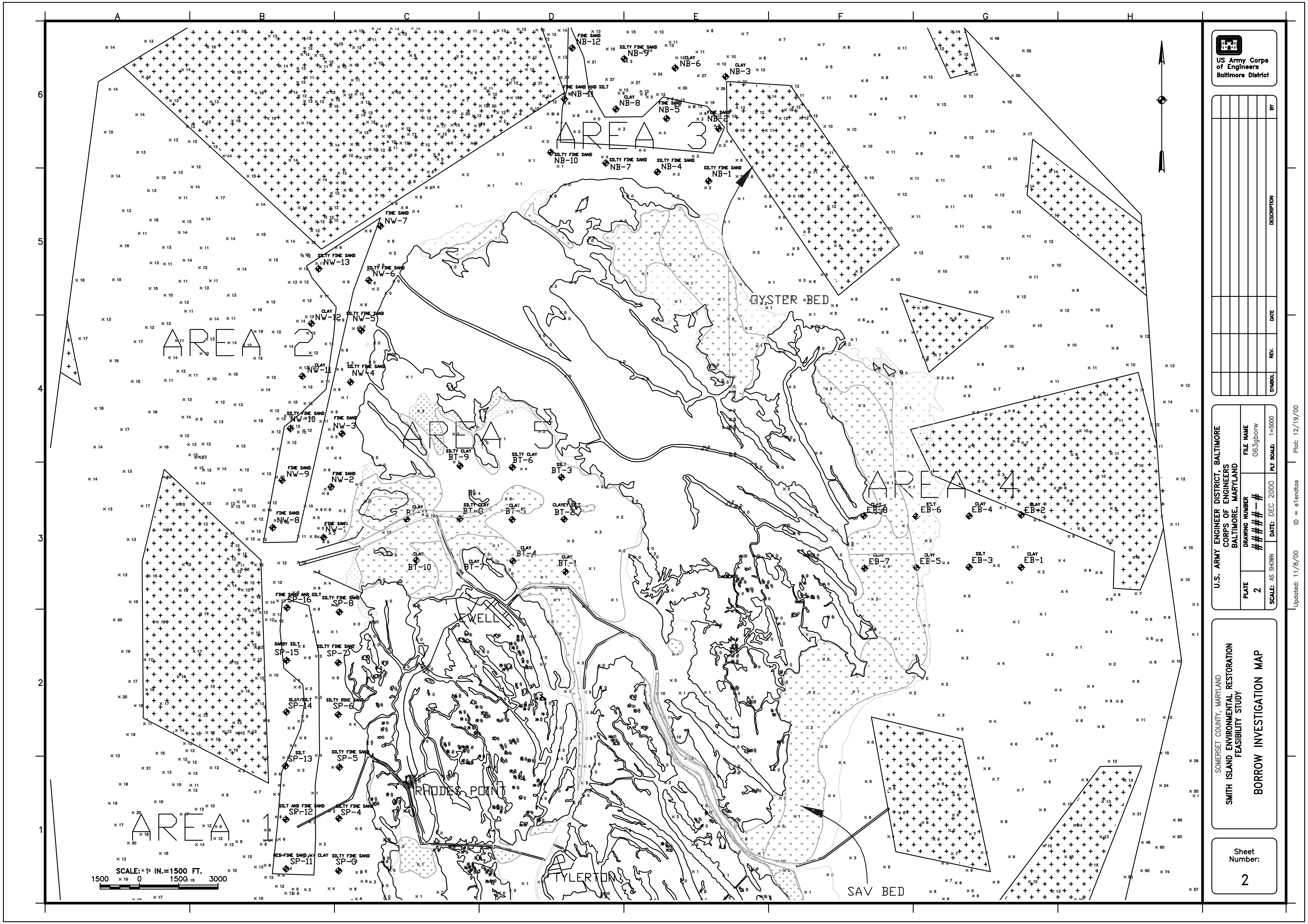
FEASIBILITY STUDY

GENERAL PLAN & LEGEND

1



AREA 1
AREA 2
AREA 3
AREA 4
AREA 5
OYSTER BED
SAV BED
EWELL
RHODES POINT
TYLERTON
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U.S. ARMY ENGINEER DISTRICT, BALTIMORE
CORPS OF ENGINEERS
BALTIMORE, MARYLAND
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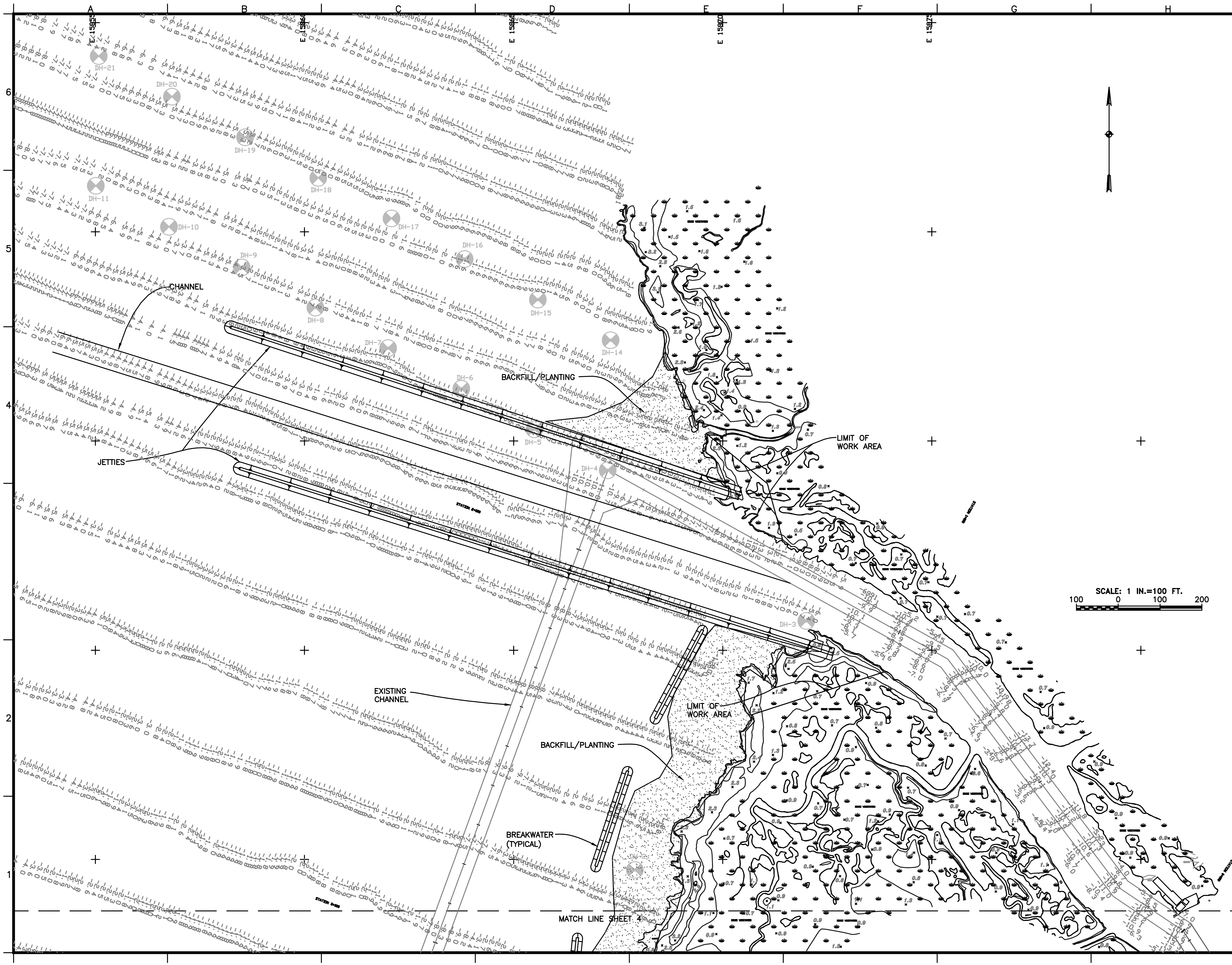

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SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

RHODES POINT PLAN

Sheet Number:
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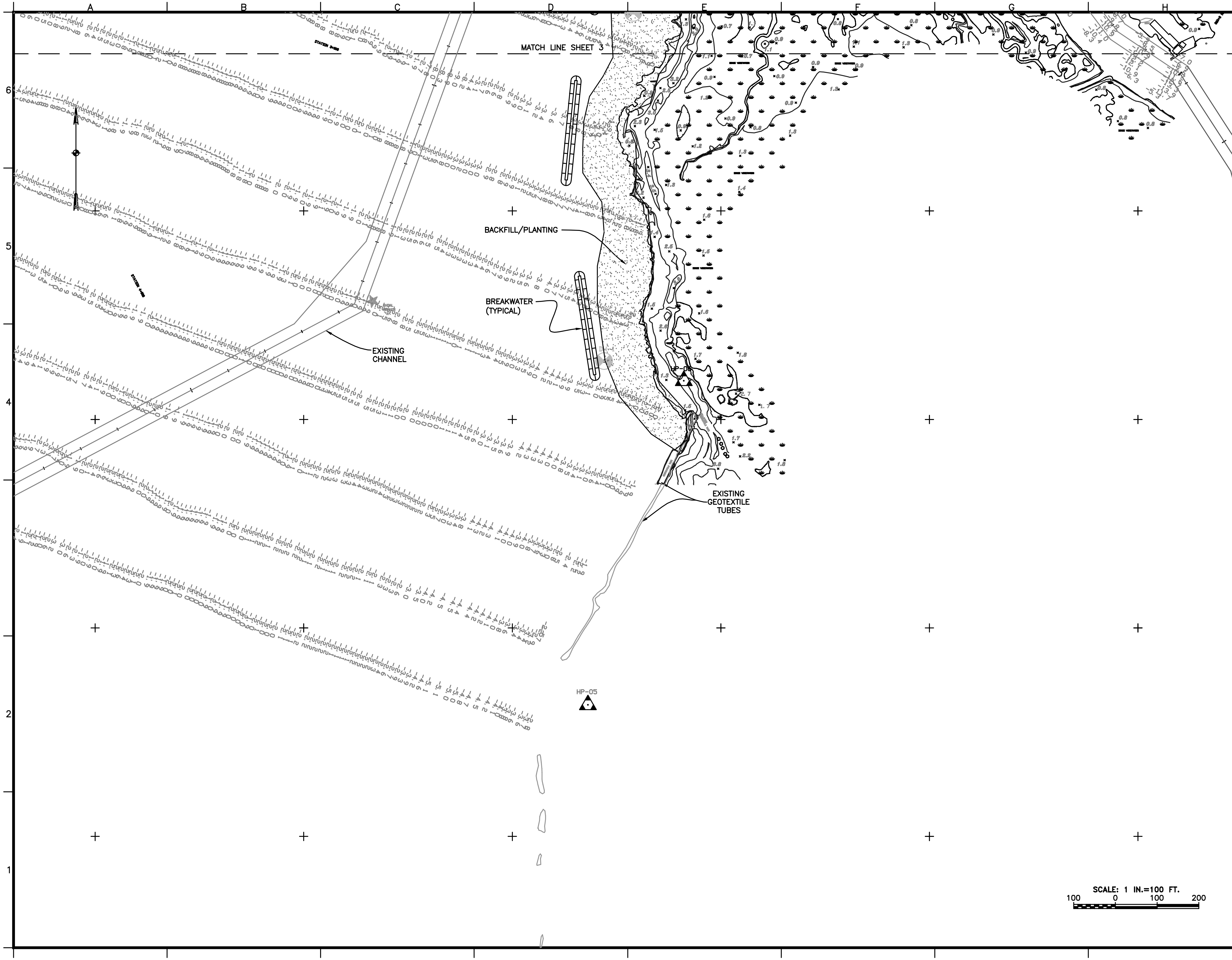

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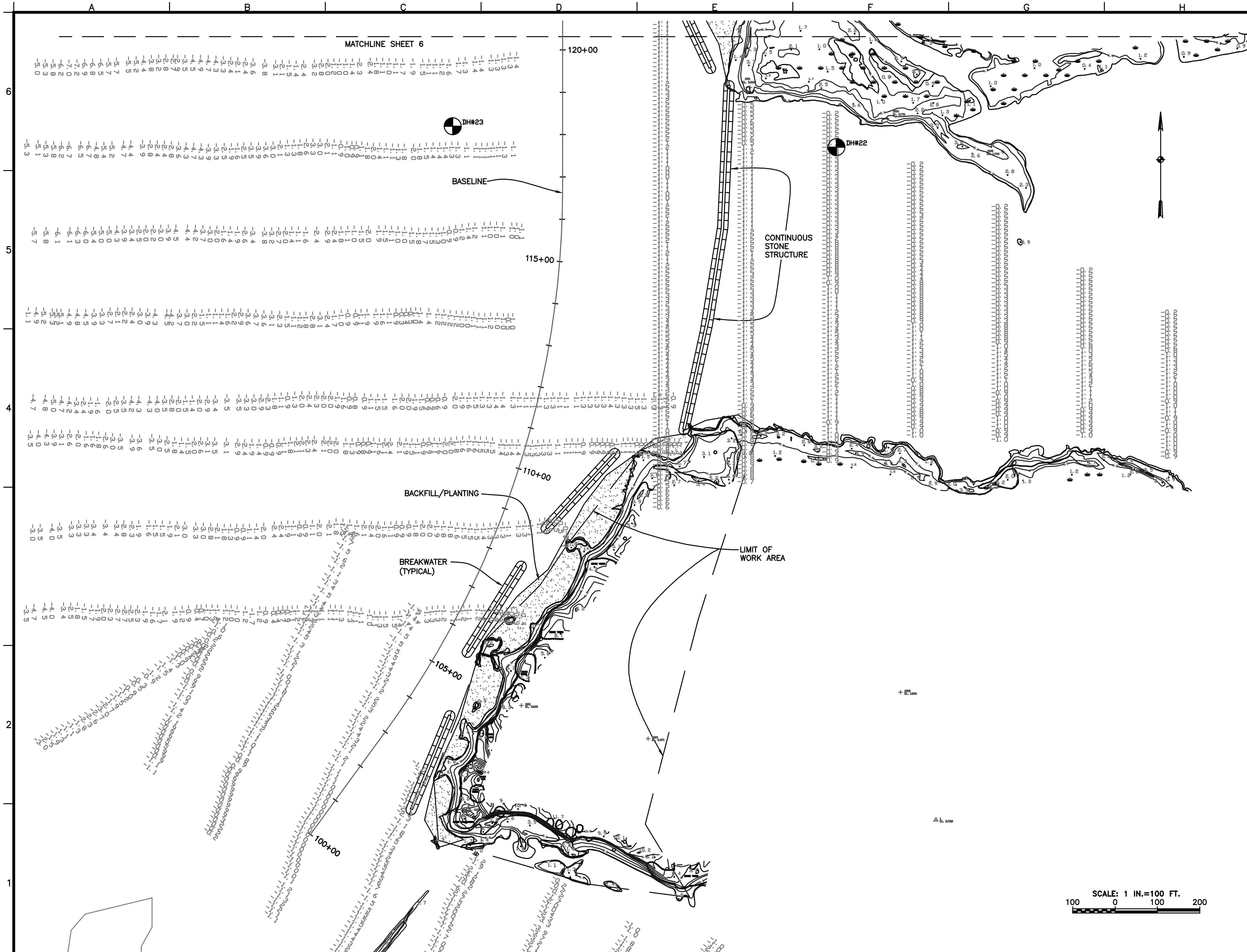
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

RHODES POINT PLAN

Sheet Number: 4



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SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

WESTERN SHORELINE PLAN

Sheet
Number:
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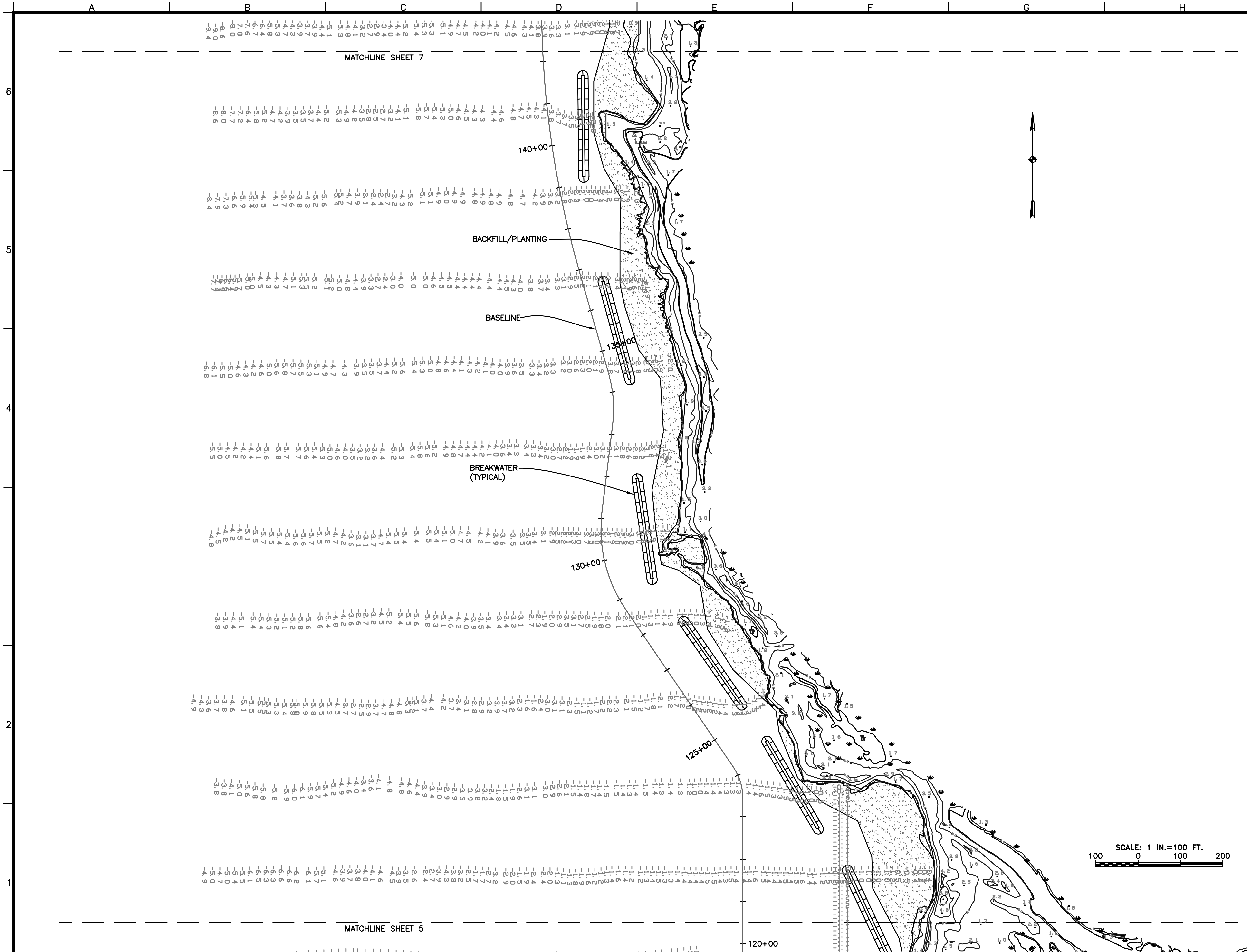

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SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

WESTERN SHORELINE PLAN

Sheet Number:
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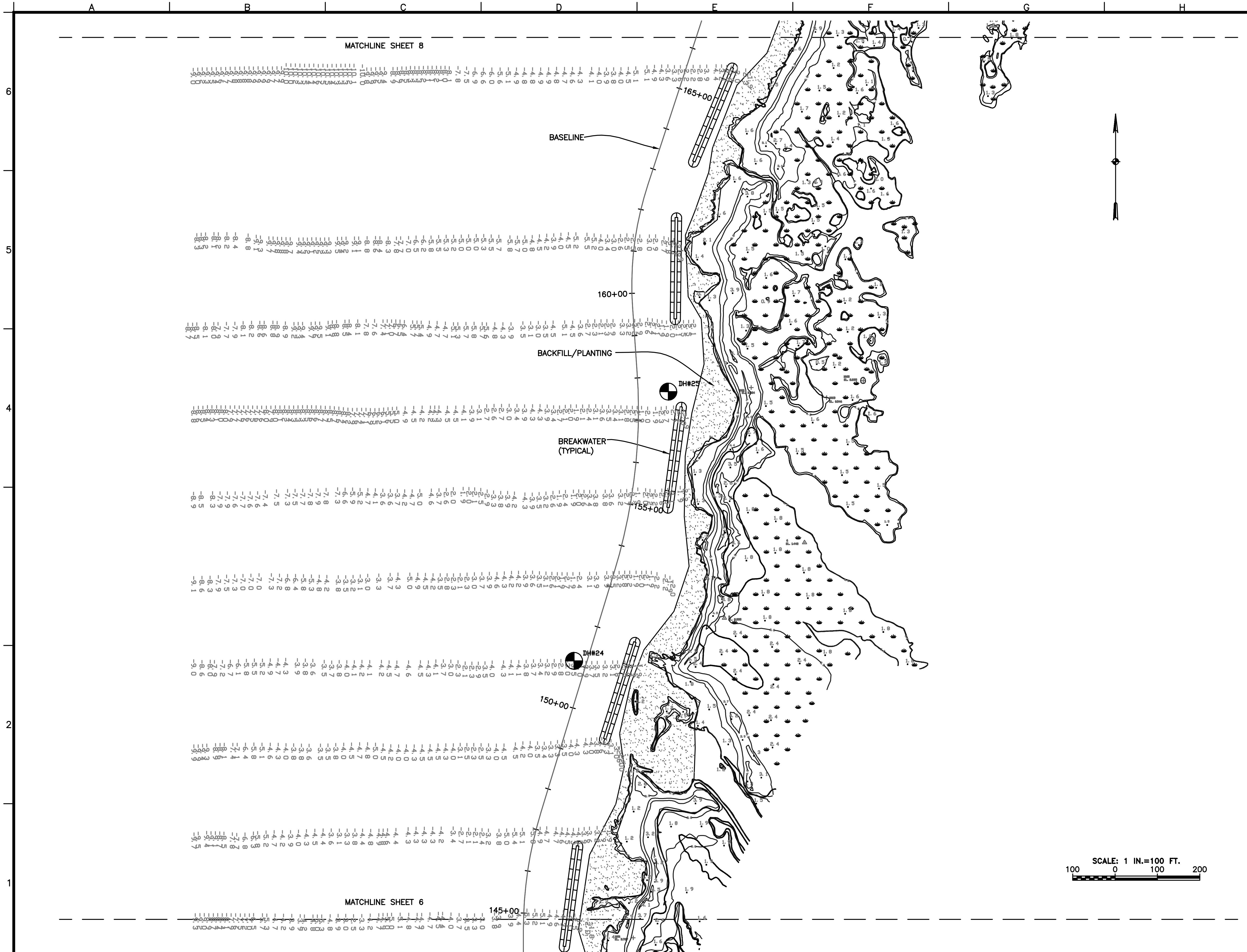

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SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

WESTERN SHORELINE PLAN

Sheet Number: 7

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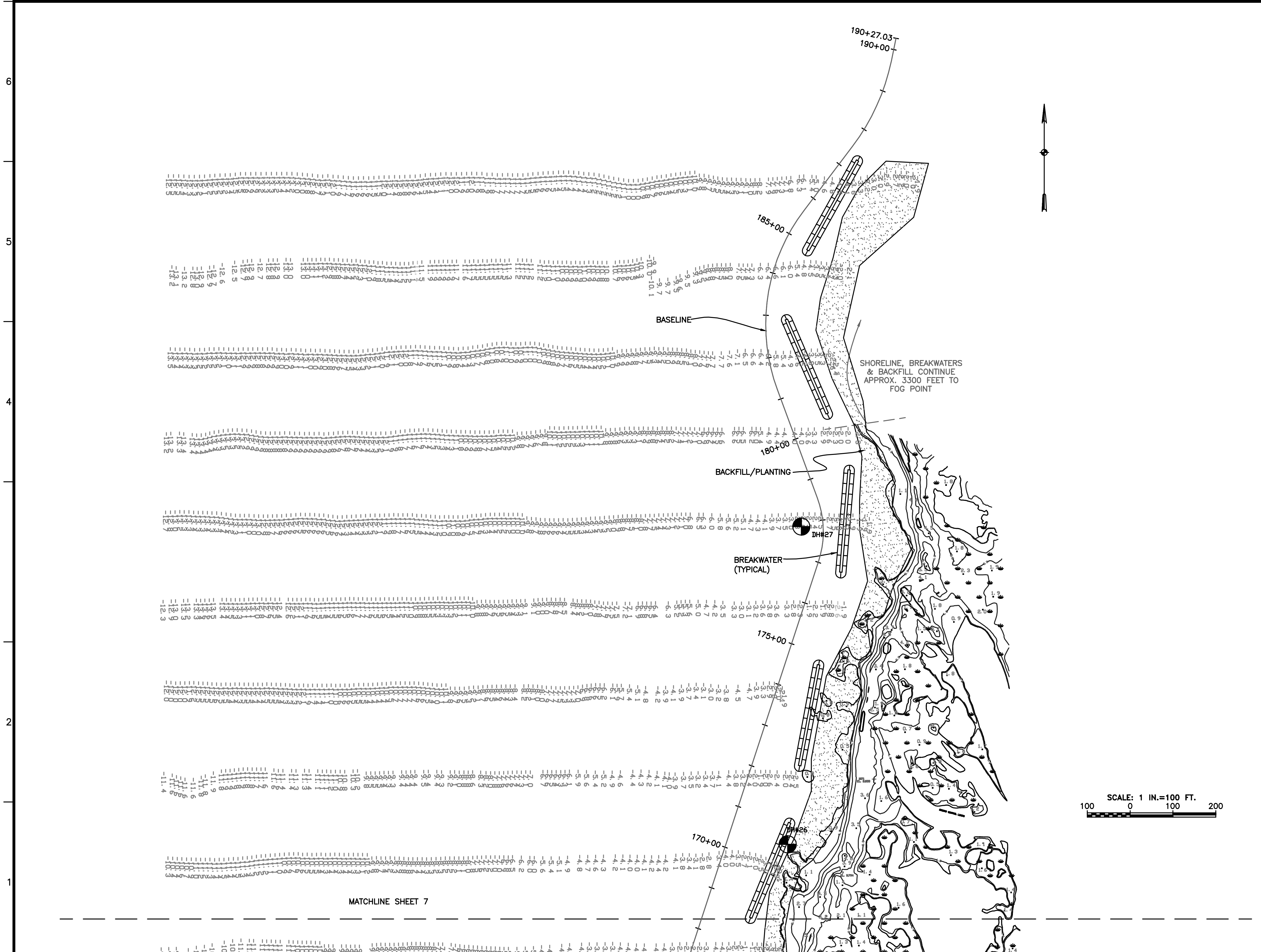

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SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

WESTERN SHORELINE PLAN

Sheet Number:
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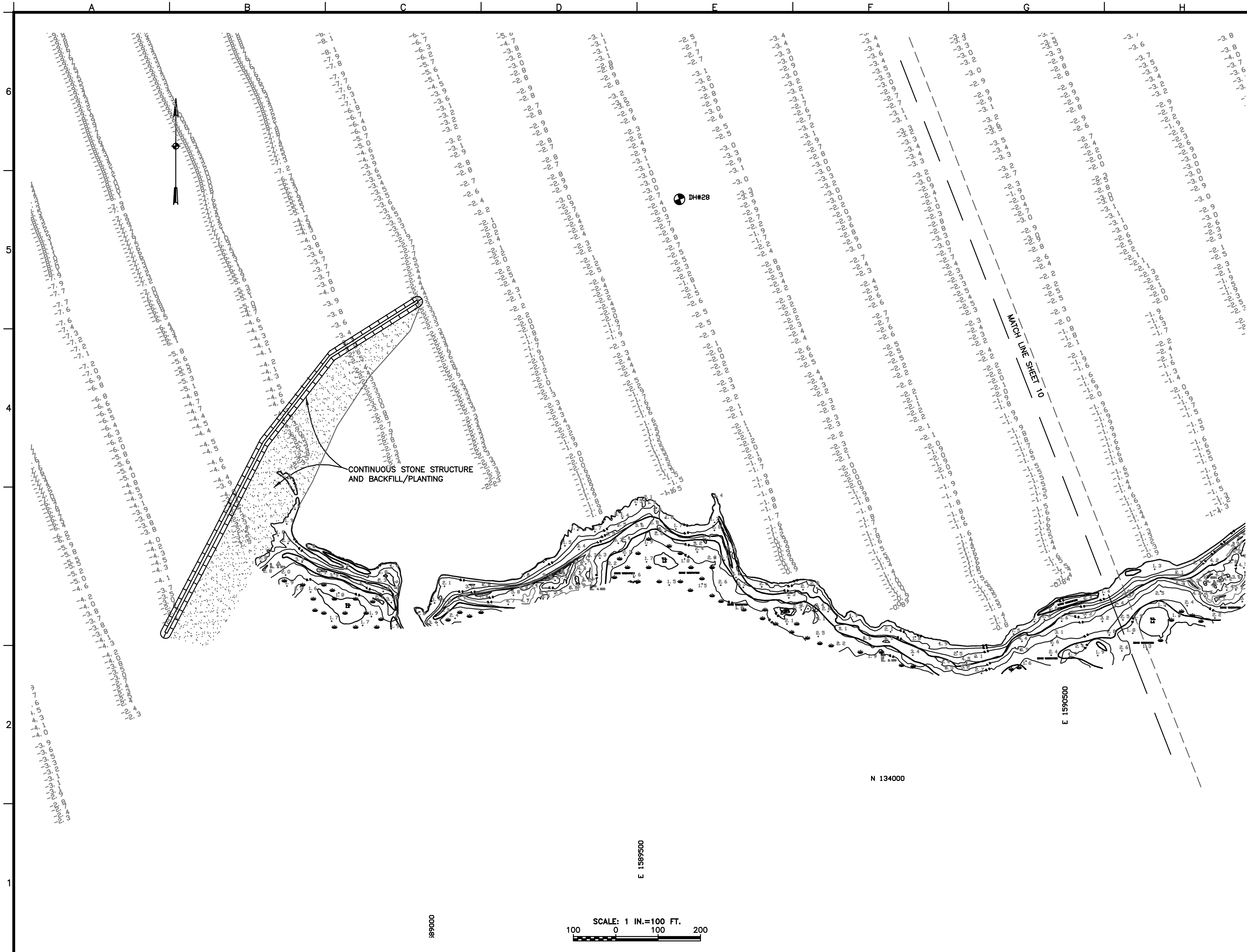

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SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

FOG POINT COVE PLAN

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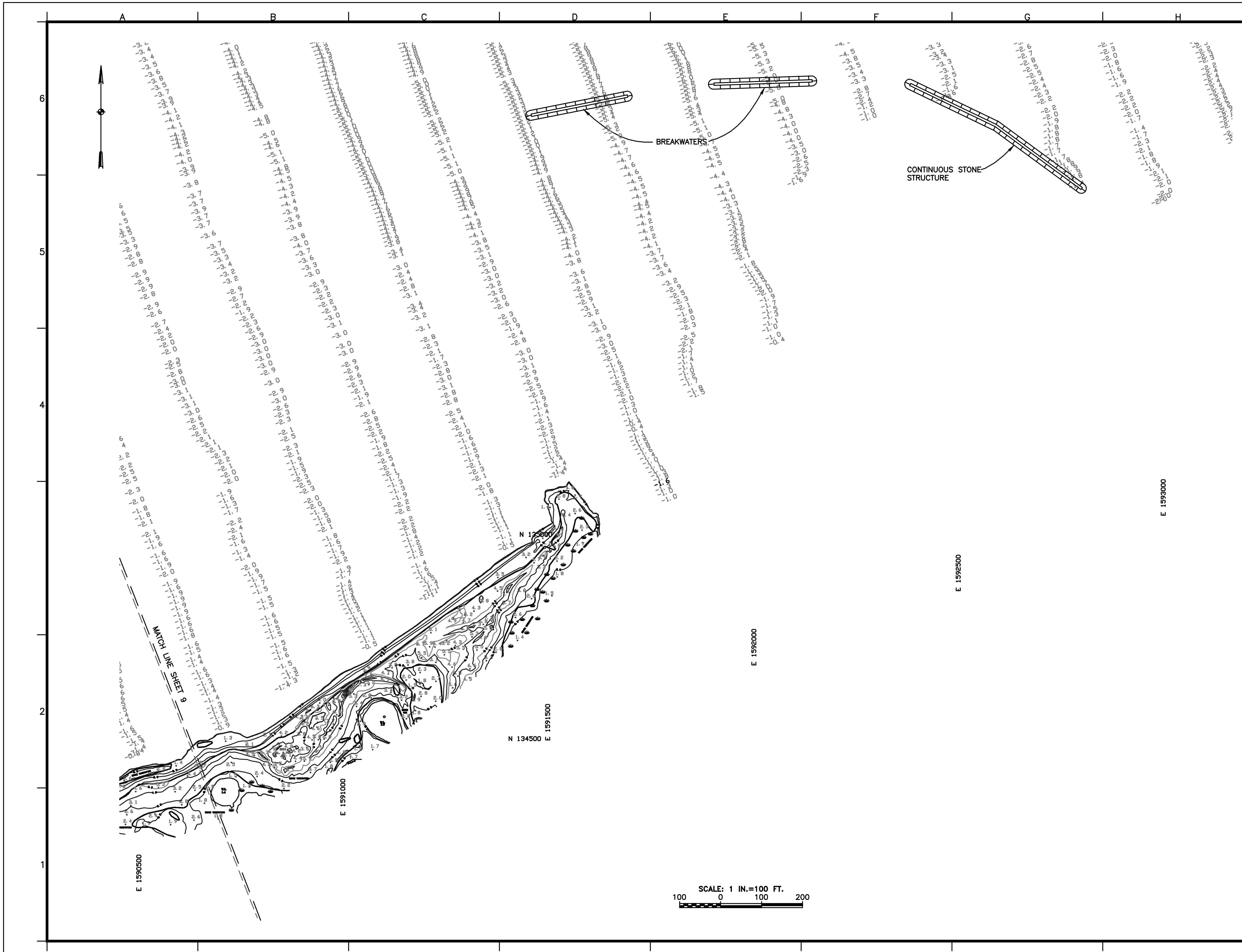

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SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

FOG POINT COVE PLAN

Sheet Number:
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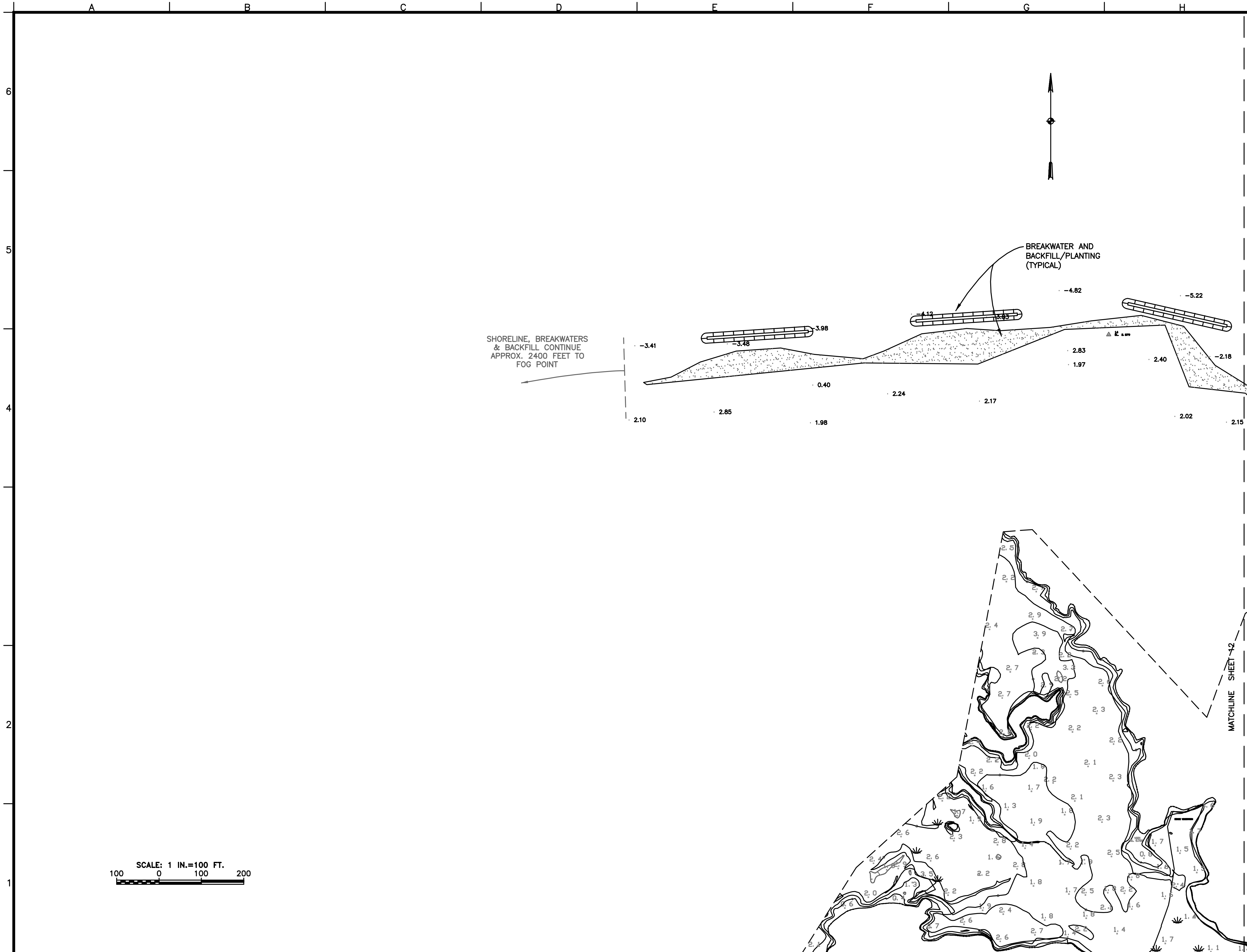

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BALTIMORE, MARYLAND

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SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

BACK COVE PLAN
NORTH PENINSULA & SHORELINE

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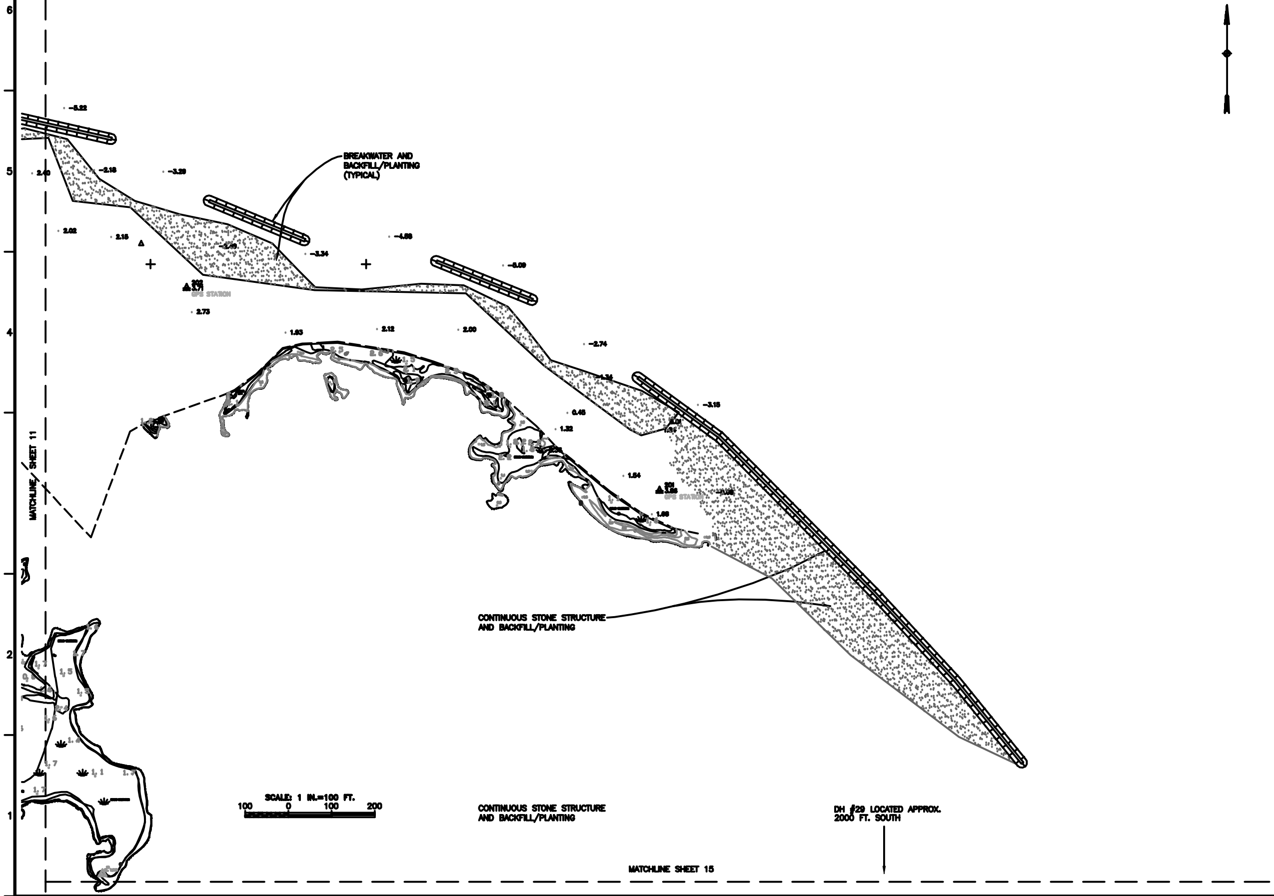

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SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

BACK COVE PLAN
NORTH PENINSULA & SHORELINE

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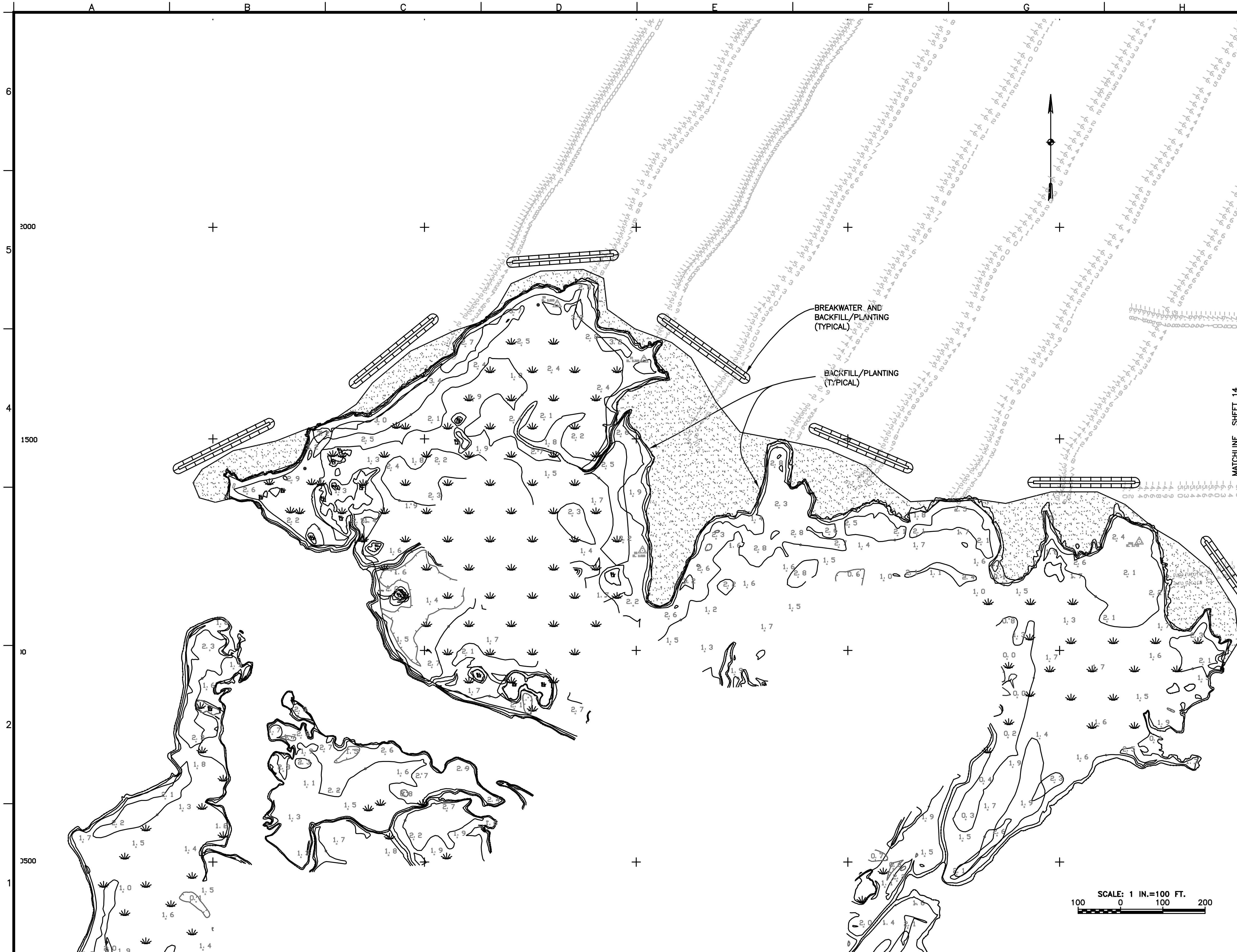

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SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

BACK COVE PLAN
SOUTHEAST SHORELINE

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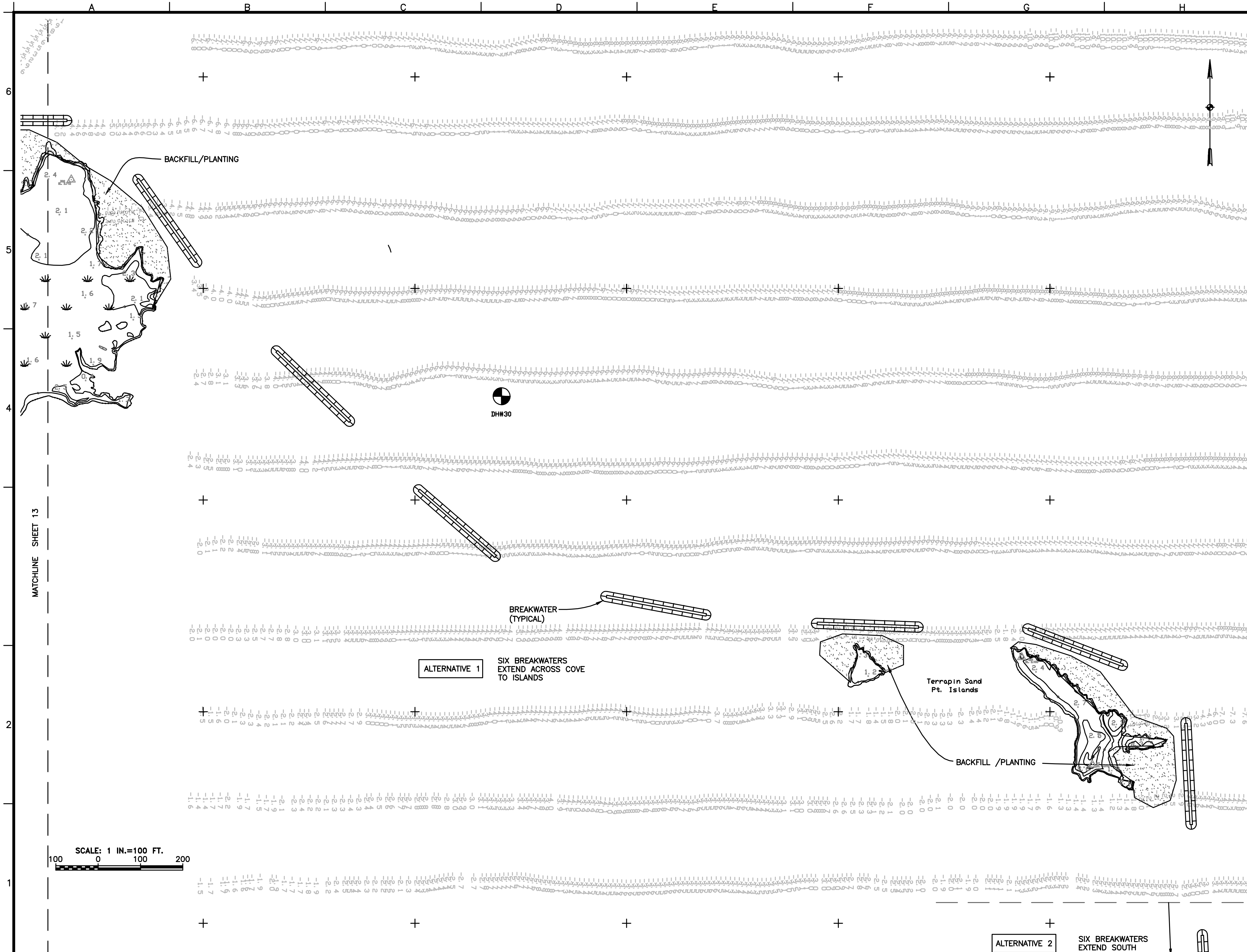
10/12/00



US Army Corps of Engineers
Baltimore District

SYMBOL	REV.	DATE	DESCRIPTION	BY

U.S. ARMY ENGINEER DISTRICT, BALTIMORE
CORPS OF ENGINEERS
BALTIMORE, MARYLAND

PLATE 14 | DRAWING NUMBER ####-# | FILE NAME 063plnbc

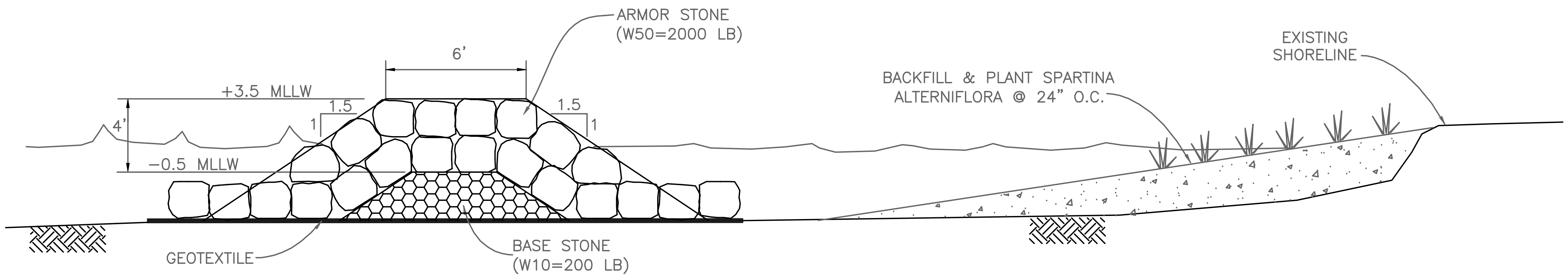
SCALE: AS SHOWN | DATE: DEC 2000 | PLT SCALE: 1=1

SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

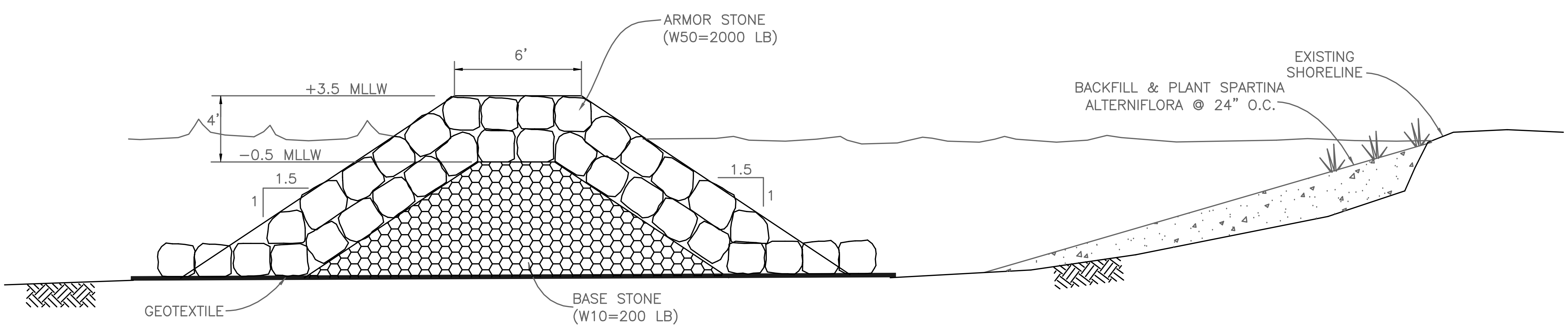
TERRAPIN SAND COVE PLAN

Sheet Number:
14

Updated: 12/4/00 ID = e1endtas Plot: 12/19/00



BREAKWATER – WATER DEPTH −2 MLLW & LESS
NOT TO SCALE



BREAKWATER – WATER DEPTH BELOW −2 MLLW
NOT TO SCALE

US Army Corps of Engineers Baltimore District

SYMBOL	REV.	DESCRIPTION	DATE	BY

U.S. ARMY ENGINEER DISTRICT, BALTIMORE
CORPS OF ENGINEERS
BALTIMORE, MARYLAND

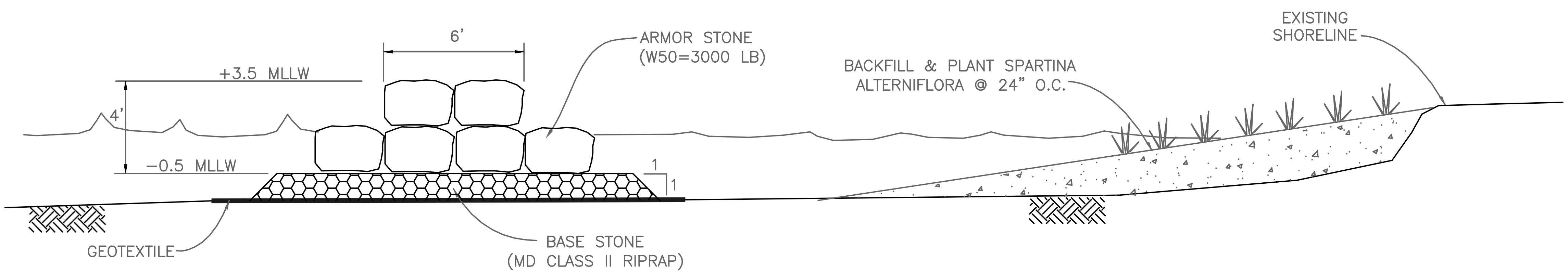
PLATE 15 | DRAWING NUMBER ####-# | FILE NAME 063csect3a
SCALE: AS SHOWN | DATE: DEC 2000 | PLT SCALE: 1 = 10

Updated: 12/15/00 ID = e1endtas Plot: 12/19/00

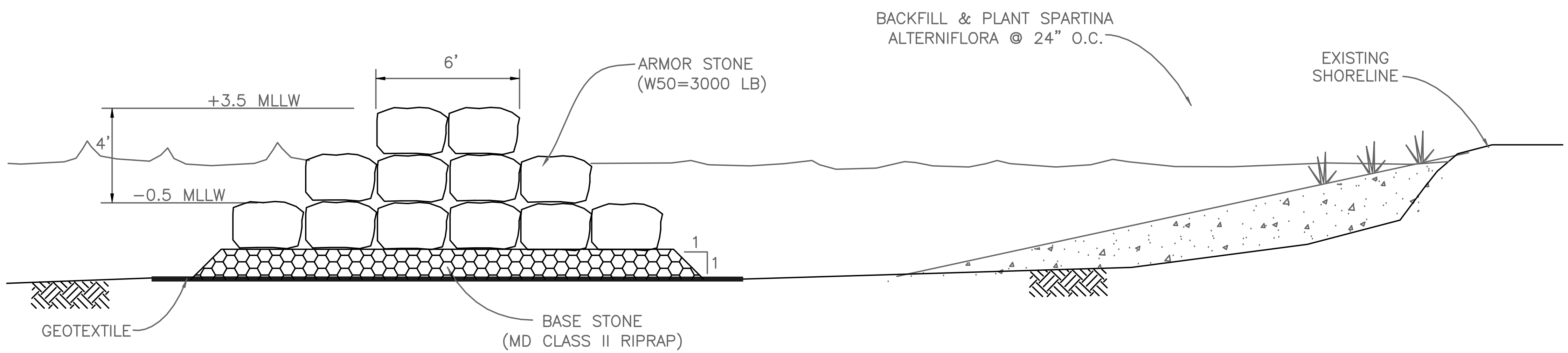
SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

TYPICAL SECTIONS
(CONVENTIONAL)

Sheet Number:
15



BREAKWATER – WATER DEPTH −2 MLLW & LESS
NOT TO SCALE



BREAKWATER – WATER DEPTH BELOW −2 MLLW
NOT TO SCALE

US Army Corps of Engineers
Baltimore District

SYMBOL	REV.	DATE	DESCRIPTION	BY

U.S. ARMY ENGINEER DISTRICT, BALTIMORE
CORPS OF ENGINEERS
BALTIMORE, MARYLAND

PLATE: 16 | DRAWING NUMBER: ####-# | FILE NAME: 063csect4a
SCALE: AS SHOWN | DATE: DEC 2000 | PLT SCALE: 1 = 10

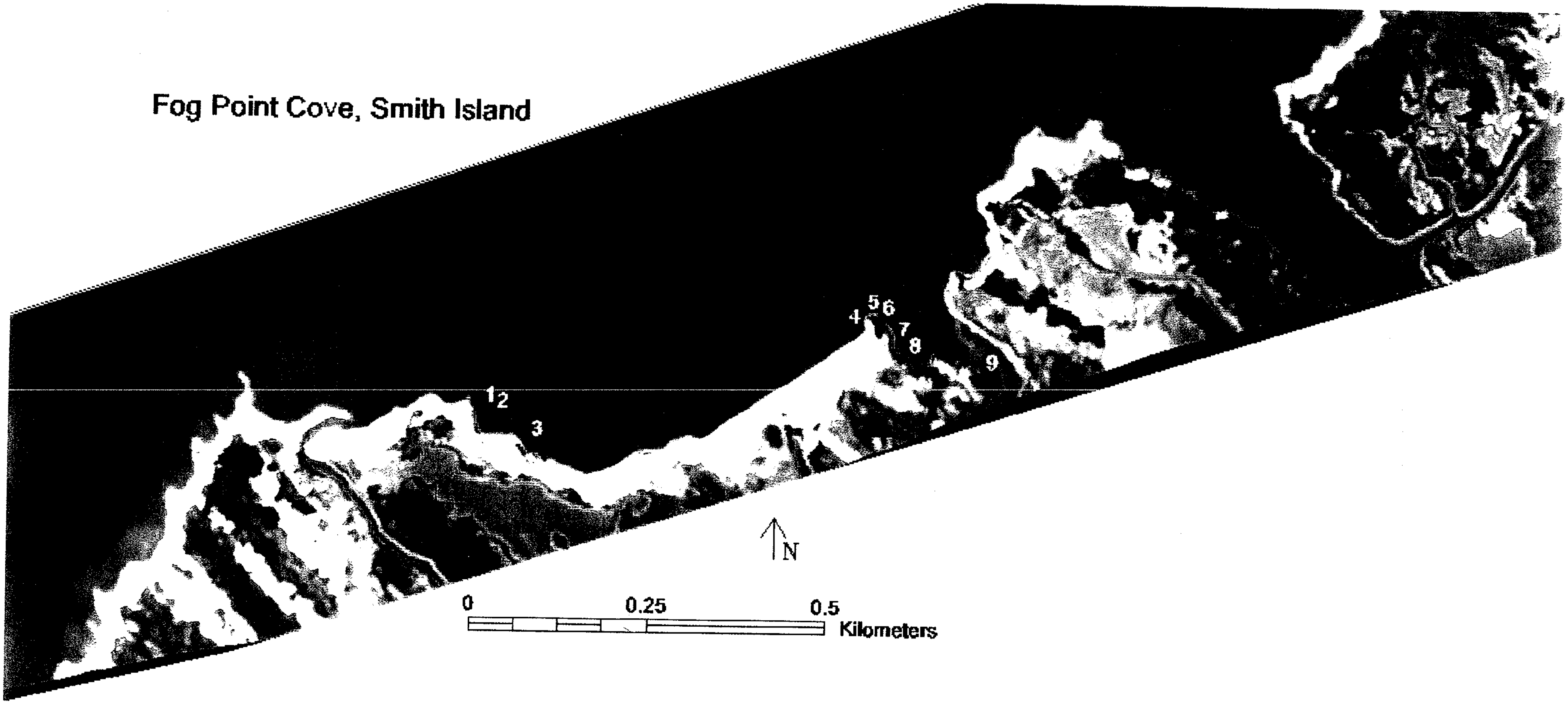
SOMERSET COUNTY, MARYLAND
SMITH ISLAND ENVIRONMENTAL RESTORATION
FEASIBILITY STUDY

TYPICAL SECTIONS (REDUCED VOLUME)

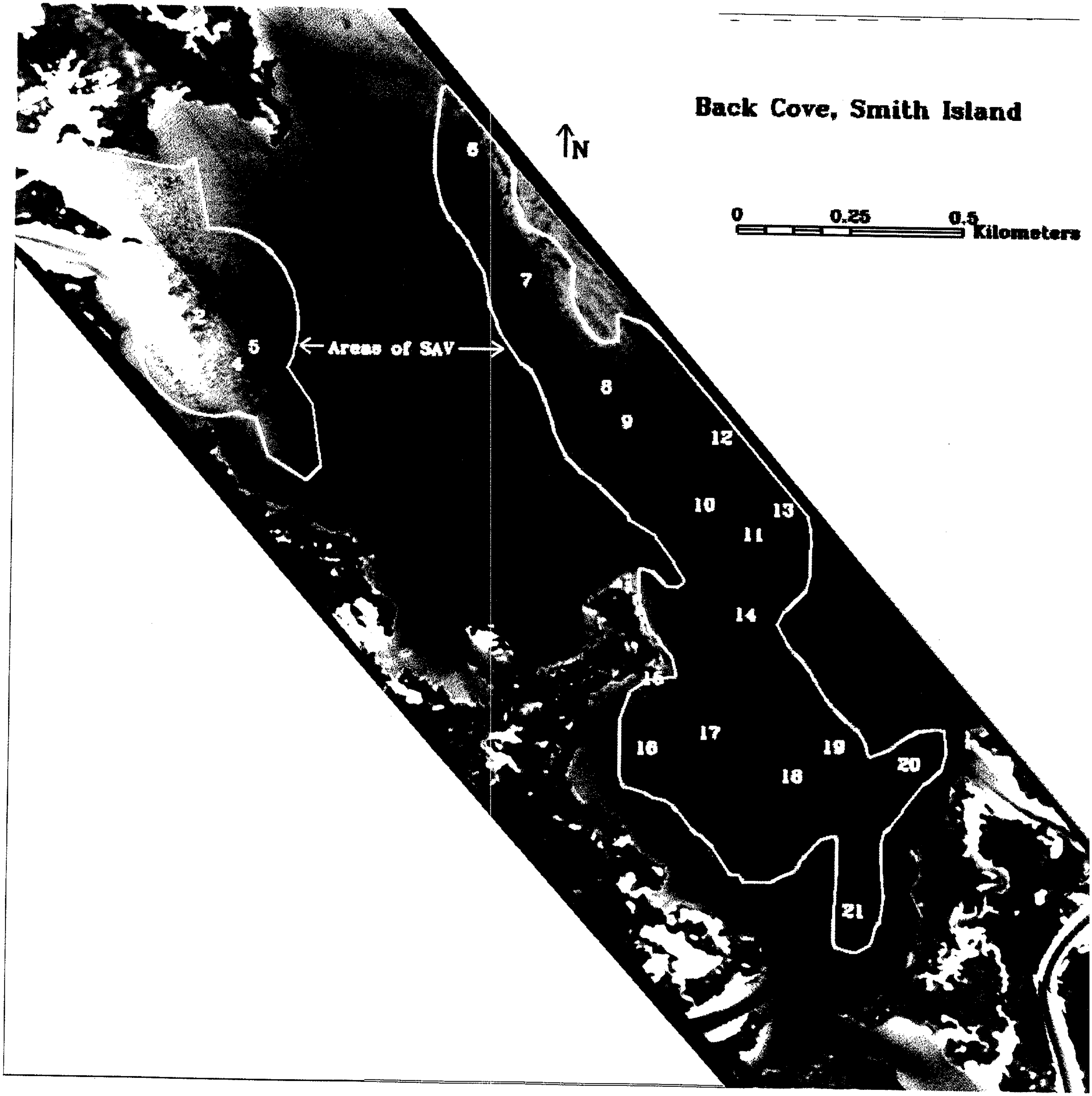
Sheet Number: 16

Updated: 12/15/00 ID = e1endtas Plot: 12/19/00

Fog Point Cove, Smith Island



Sheet 17


Back Cove, Smith Island
N
0
0.25
0.5
Kilometers
Areas of SAV
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

Sheet 18